



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **Enterprise Command and Control Requirements and Common Architecture on US Navy Surface Combatants**

by

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Prepared for: Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering

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## **ABSTRACT**

Across the U.S. Navy, each new ship class implements a new command and control (C2) system design, leading to separate design and development efforts, training pipelines, support requirements, and upgrade activities. This project serves as an initial step in determining whether the Navy can consolidate C2 systems by defining a common C2 system architecture and requirements that can be applied across all surface combatants for the Surface Warfare and Maritime Interception Operations missions. The project applied a systems engineering process consisting of a needs analysis, functional analysis, and modeling and cost analysis. The needs analysis defined key user objectives and needs and identified threats to Navy platforms. The functional analysis included the core tasks of requirements definition and enterprise architecture. The modeling and cost analysis task verified the C2 system architecture and evaluated possible training course hour savings. The project found that the definition of a common set of C2 system requirements and system architecture is feasible and does provide possible life cycle cost savings to the Navy. In order to fully evaluate a proposed common C2 system, further work will be required, expanding the analysis to other missions and assessing the cost impacts of a common C2 system

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# **EXECUTIVE SUMMARY**

The Naval Surface Warfare Center (NSWC) capstone team project is focused on eliminating redundancies in the U.S. Navy's development and deployment of Command and Control (C2) systems across multiple platforms, which could result in potential cost savings. Senior leaders across the Acquisition community acknowledged deficiencies of acquisition effort stemming from the fact that various ship platforms utilize different C2 systems to accomplish similar ship functions. This redundancy results in potentially unnecessary cost to maintain different configurations, training curricula, logistics support, and upgrade plans. This capstone project develops a common set of C2 functional requirements and a C2 enterprise architecture applicable to Guided Missile Cruiser, Destroyer and Frigate class platforms.

The purpose of this project is to test the assertion that a common architecture will result in cost savings to the Navy, and also to demonstrate a methodology to develop a common architecture. Acknowledging that development of a complete surface combatant C2 architecture is a complex and resource intensive task, a method is needed to bound the scope of the problem for the capstone project. For this reason, the project focuses on two representative mission threads (surface warfare and maritime interception operations) to bound the requirements and architecture development, with the intent that the same processes in this project could be scaled to other, larger applications.

This project uses a tailored system engineering process based upon the Defense Acquisition University systems engineering process model to develop a common architecture. The systems engineering emphasis is organized into three phases: Needs Analysis, Functional Analysis, and Modeling and Simulation. The Needs Analysis phase identifies the aspects of C2 that are of greatest concern and interest to the U.S. Navy. These include supporting the entire surface warfare kill chain, positive identification of contacts utilizing all sensors, integration of off-board sensors into the tactical picture, supporting automated identification, supporting distributed weapons control, real-time sensor netting and preplanned responses, and employing non-kinetic and non-damaging effects. Additionally, a threat assessment is conducted during this phase to analyze the range of surface threats likely to be presented to a C2 system during operations.

Mission system functional requirements are developed during the Functional Analysis phase based on information contained within the Navy Tactical Task List, Navy Surface Warfare Manual, various Joint Publications, stakeholder interviews, and also derived from mission thread analysis. A significant aspect of the requirements effort is that the higher level joint publications are used to tailor the requirements to the mission without targeting a specific, existing C2 system. A value system design is created to describe the objectives, measures of effectiveness and performance, and threshold values for each of the developed requirements. Architecture products are developed for the high-level operational concept (OV-1), operational activity model (OV-5), and systems functionality description (SV-4).

The Modeling and Analysis phase is used to validate the architecture model and to examine a methodology to evaluate potential cost savings to the Navy. The simulation capability of CORE, a commercially available systems engineering and design software tool, and Colored Petri Nets (CPN) are used to validate the consistency and execution of the architecture. The training curricula for Aegis and Ship Self Defense System (SSDS) are used as a comparison study to validate the assumption that cost savings can be achieved by developing a common enterprise architecture. Common training courses between the two systems and the hours required to complete the training for each system are mapped to the functions defined in the Functional Analysis to ensure that the training covered the relevant C2 functions. Cost savings in the form of man-hours can then be identified in areas of potential training redundancy.

The project created a list of C2 system requirements and a validated common functional architecture that could be applied across multiple platforms. The project also demonstrated that a common system architecture could result in reduced training costs throughout the lifecycle of the system. Thus, the report recommends that the Navy acquisition community pursue opportunities to design and develop common system architectures as cost savings initiatives.



# **I. INTRODUCTION**

## **A. PROBLEM STATEMENT**

Surface navy ship C2 systems are the means by which the commander's intent is made clear, allowing the crew to know what is required to meet the mission. C2 systems have evolved from 19th century signal flags to modern computerized command and decision systems [Edwards, 2008]. The 21st century US Navy defines C2 as "The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission" [Office of the Chief of Naval Operations, 2007, Glossary-1]. An important aspect to draw from this definition is that the Command and Control system includes people, hardware and software; all of which are part of, or support, the authority and direction process.

Across the Surface Navy Enterprise, each new ship class implements a new C2 design for the combat system with a unique set of system requirements and associated architecture. The U.S. Navy currently develops and deploys multiple major surface C2 systems: the Aegis Command and Decision system on Aegis cruisers and destroyers, the Ship Self Defense System on aircraft carriers and large deck amphibious ships, and the Total Ship Computing Environment currently planned for DDG-1000. Each of these unique C2 systems has separate design and development efforts, training pipelines, support requirements, and upgrade activities. Life cycle costs associated with maintaining distinct development, test, and support activities for each C2 system are very high. Capability upgrades to these systems are costly because systems are complex, tightly coupled, and tied to specific vendors who are protected against competition by contractual barriers and large capital requirements. Upgrades also take too long to reach the fleet, possibly being obsolete by the time they get there [Edwards, 2008]. System operators who are trained and experienced in one C2 system typically are not qualified to operate the others, which limits the Navy's flexibility in manning platforms.

To address these problems, the surface navy acquisition community has assumed that there is potential for significant cost savings, faster introduction of war fighting capability, and improvements to surface fleet readiness if a common set of core C2 components were developed

for all surface combatants [Benedict, 2008]. One approach to achieve a core set of C2 components is to define a common C2 architecture following systems engineering principles.

In alignment with the surface navy's strategy, this capstone project focuses on the development of a common set of requirements and C2 architecture, to support two specific mission threads for implementation on multiple surface ship platforms. As a metric for affordability, the project will evaluate "school house" training hours. Specifically, will a common C2 architecture help to reduce the training hours required for the operator?

## **B. PROJECT DESCRIPTION**

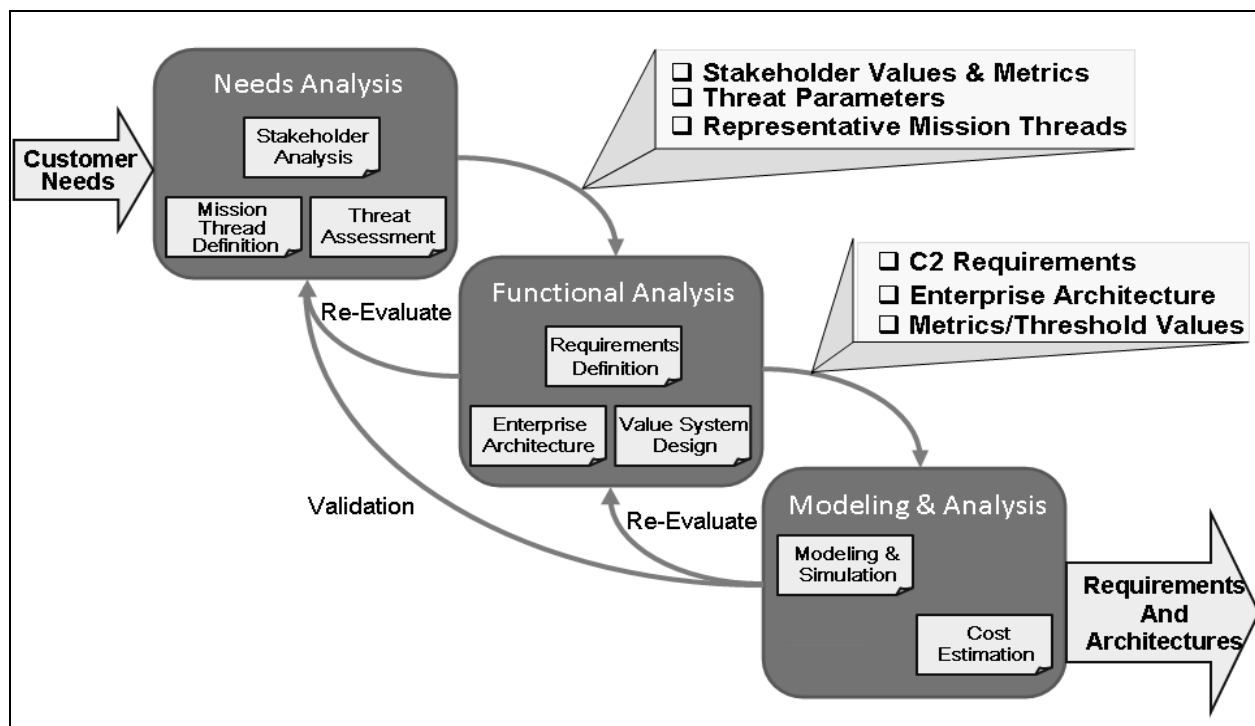
In an effort to maximize combat effectiveness, surface combatant platforms use command and control to coordinate employment of the ship's sensors and weapons, to make sense of the tactical situation, and to plan and coordinate their activities with those of other units in the area of operations. Department of Defense Architecture Framework (DoDAF) products provide a DoD-accepted approach for describing an architecture capable of performing these C2 functions, and were used to define and develop an enterprise-level C2 architecture that is independent of existing systems or platforms. This architecture was developed to support functionality normally performed by combatants normally assigned surface warfare as a primary mission area, such as cruisers, destroyers and frigates. The expectation is that the concepts and processes developed in this project are scalable to broader surface platform applications.

The DoDAF products are based upon two representative mission threads and associated C2 functionality. Two mission threads were selected for this project to capture the desires and needs of the stakeholders and to scope the focus of the project into manageable overlapping areas. The mission threads assessed were: conduct surface warfare (SUW) operations and conduct maritime interception operations (MIO). The selected mission threads cover both combat and non-combat conditions and represent two unique roles of many missions that a C2 system should be capable of performing in a specified area of operation. The conduct SUW thread includes the ability of the C2 system to process and assess sensor contacts, track, identify, and report possible targets as well as support engagement decisions while maintaining and supporting the Common Tactical Picture. The conduct MIO thread includes the ability of the C2 system to exchange information during a MIO event in order to support battlespace awareness and decision-making. In short, SUW and MIO were determined to be broad enough yet focused enough to represent the development of a common C2 architecture.

A set of enterprise C2 requirements was then developed, based on the SUW and MIO mission threads. The common set of C2 requirements and mission threads were instrumental in the development of an enterprise-level C2 architecture. Several of the architecture descriptions are presented as DoDAF products. Finally, a cost analysis, in terms of training hours, was performed to establish avenues in which the US Navy may realize savings by using a common set of C2 requirements and architecture. This report documents the methodology and the process used to identify the superset of requirements, providing a traceable and repeatable means for developing other C2 architectures for additional mission threads.

### C. SYSTEMS ENGINEERING PROCESS

A tailored system engineering process illustrated in Figure 1 was employed to establish the C2 enterprise architecture and requirements. This process is an adaptation of the systems engineering process published in System Engineering Fundamentals [Defense Acquisition University, 2001].



**Figure 1: NSWC Tailored System Engineering Process**

The Systems Engineering (SE) process model for this project consists of three phases: Needs Analysis, Functional Analysis, and Modeling and Analysis. Each successive phase builds upon the previous phase.

The tailored process consists of three iterative phases which began with the Needs Analysis phase. This phase focused on research to understand the stakeholders' needs and expectations, and also to gain more insight into the problem statement. This phase also included investigation of the two mission threads and threats against the platforms. These mission threads and threats were analyzed in order to understand the operational needs and objectives of command and control. The mission threads also provided project context for the definition of C2. (For example, the mission threads assumed that the C2 system included human, hardware, and software components.) Stakeholder Analysis helped to identify system functionality. Mission thread definition helped identify additional functionality and provided context for the system. The threat assessment provided platform threat information. The information gathered within the Needs Analysis phase served as the input for the Functional Analysis phase and was used as the basis of the C2 architecture and requirements development.

In the Functional Analysis phase, the system-level requirements and the functional architecture for the C2 aspects of the platform were defined. The information collected in the Needs Analysis phase (e.g. needs, threats, functionality) was documented as requirement "shall" statements. These written requirements represent the attributes and capabilities that the C2 system must possess to be useful and meet the needs of the stakeholders. These requirements are then translated into functions captured in the functional architecture using DoDAF. Needs Analysis was then re-evaluated to determine if further stakeholder input was needed for clarification, if the mission threads were adequately defined, and if the threats were fully established.

The Modeling and Analysis phase provided simulation and model verification of functional architecture identified during the Functional Analysis phase. Analysis was conducted to identify methods in which the common architecture could yield potential savings in the areas of training and capability upgrades. The previous phases were re-evaluated to determine if the requirements, architecture, mission threads, and threats were adequately developed. The stakeholders were also contacted to validate the progress of the project.

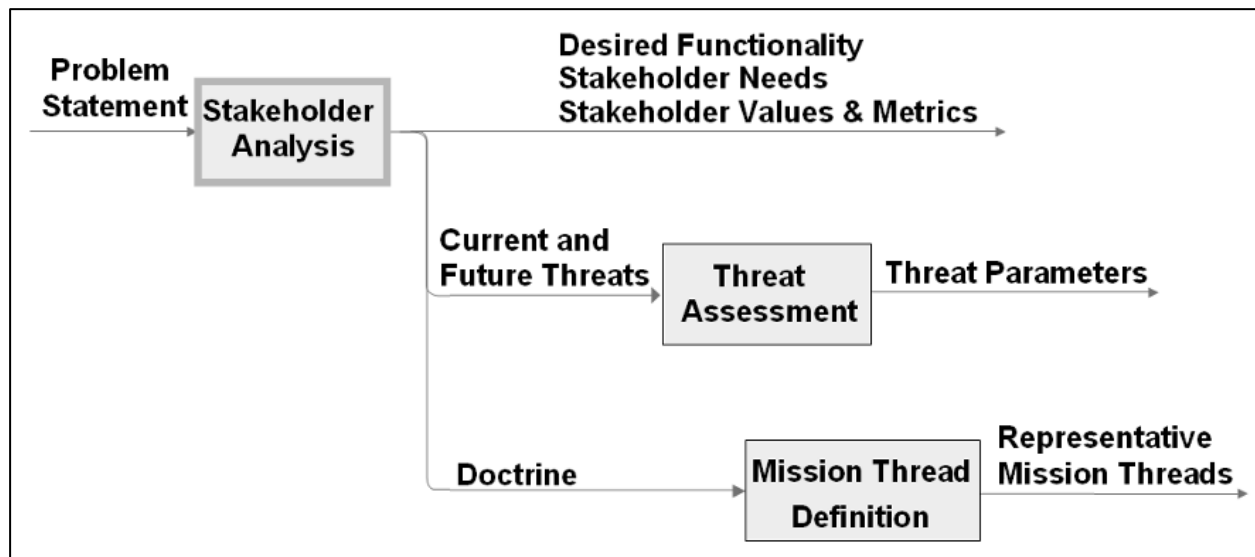
This project resulted in a documented process for developing scalable enterprise requirements and architectures, as well as specific requirement and architecture sets to support the identified project mission threads. The following sections more clearly define the phases of the process.

## 1. Needs Analysis Phase

### a. Stakeholder Analysis

The purpose of the stakeholder analysis task was to identify the stakeholders for the ship C2 system and to elicit guidance from the stakeholders and official documents to identify direction for other needs analysis tasks. As such, the stakeholder analysis did not produce any of the major end products of the project, namely the architecture and the C2 requirements, but it was still a vital step in the process. The stakeholder analysis provided foundational information for the follow-on tasks that ultimately led to the end-product development.

The stakeholder analysis was conducted based on the information in the problem statement. The stakeholder expectation of current and future threats was used in the threat assessment. The summary of naval doctrine was used to enhance the mission thread definitions. The stakeholders' desires for system functionality helped define the architecture throughout development. The stakeholders' values and metrics were incorporated into the value system design. Specific stakeholder needs were the basis for the requirements definition. The relationship between the Stakeholder Analysis task and the following tasks is depicted in Figure 2.



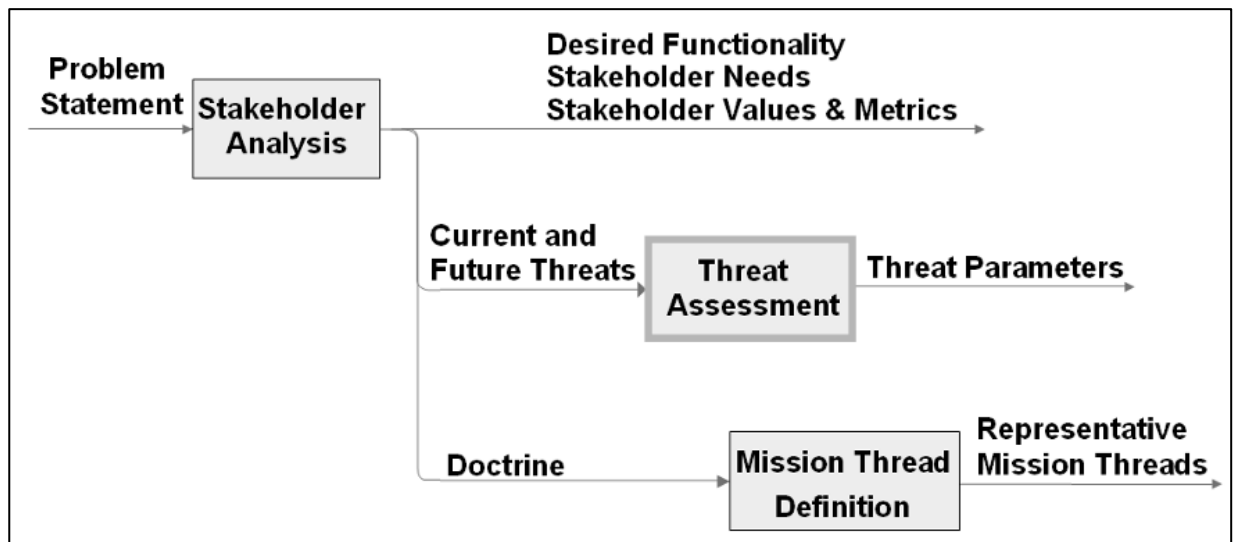
**Figure 2: Stakeholder Analysis Task Relationships**

The findings from the Stakeholder Analysis helped support the other tasks in Needs Analysis Phase, and also provided inputs into the other Phases of the SE process.

The stakeholder analysis began by identifying the key stakeholder organizations. Then the stakeholders were interviewed and a range of stakeholder documents were surveyed. Stakeholder interviews were conducted using a common set of questions. The survey of stakeholder documents ranged from high-level maritime policy to Naval Warfare Publications (NWP) and Naval Tactics, Techniques and Procedures (NTTP). These documents are listed in the stakeholder analysis section.

### ***b. Threat Assessment***

The objective of the threat assessment was to survey current and future threats to U.S. Navy platforms with the purpose of influencing the requirements definition task. The inputs to the threat assessment were the problem statement and the stakeholder feedback on current and future threats. The primary intent of the threat assessment was to feed the threat parameters into the requirements definition task. The threat assessment was used to summarize the current and future threats and their related kinematic characteristics. The threat assessment was constrained to an unclassified level. Open sources, public sites, and publicly released U.S. government and United Nations documents are the main resources for threat specifications. Figure 3 summarizes the relationship of the Threat Definition task to other tasks. As a result from this analysis, threat parameters were established.

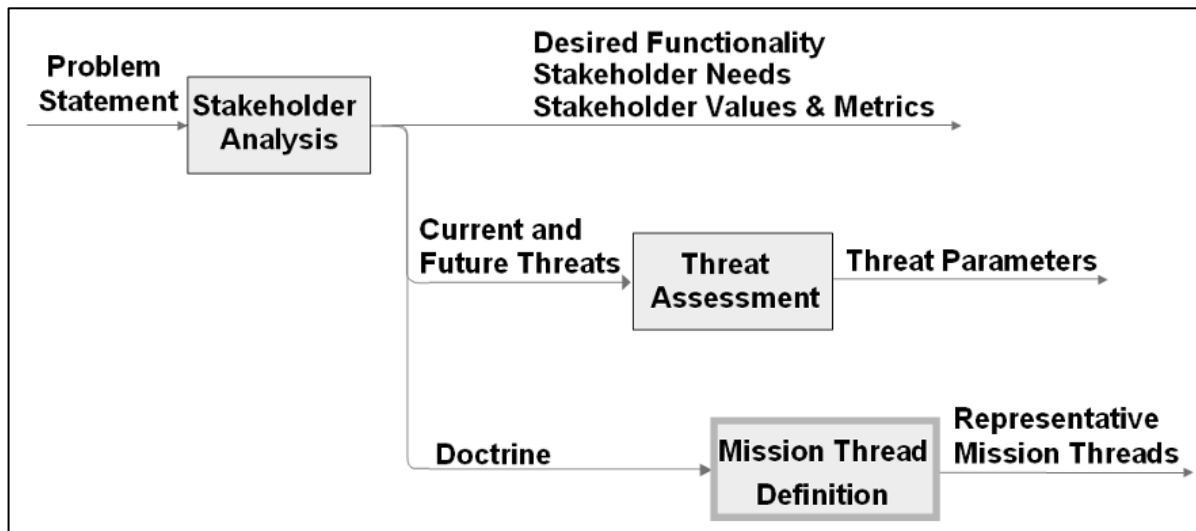


**Figure 3: Threat Assessment Task Relationships**

The Threat Assessment evaluated threats that were identified during the Stakeholder Analysis. Threat Parameters identified during this process were used to support requirements development.

### *c. Mission Thread Definition*

The development of mission threads provided a means of scoping and bounding the problem to a manageable level that would help identify the capabilities and limitations of the C2 Architecture. The threads describe representative scenarios in which the C2 system is expected to perform, and provided a framework for the functionality of the C2 system. Inputs to the mission threads came from the outputs of the stakeholders' analysis (such as summaries of Navy doctrine and publications) and were used to develop and refine the mission threads. The refined mission threads were then used to develop C2 system requirements (the requirements were derived from the mission threads to meet stakeholder needs). Figure 4 summarizes the relationship of the Mission Thread Definition tasks to the other tasks. As a result of this analysis, representative mission threads were developed.



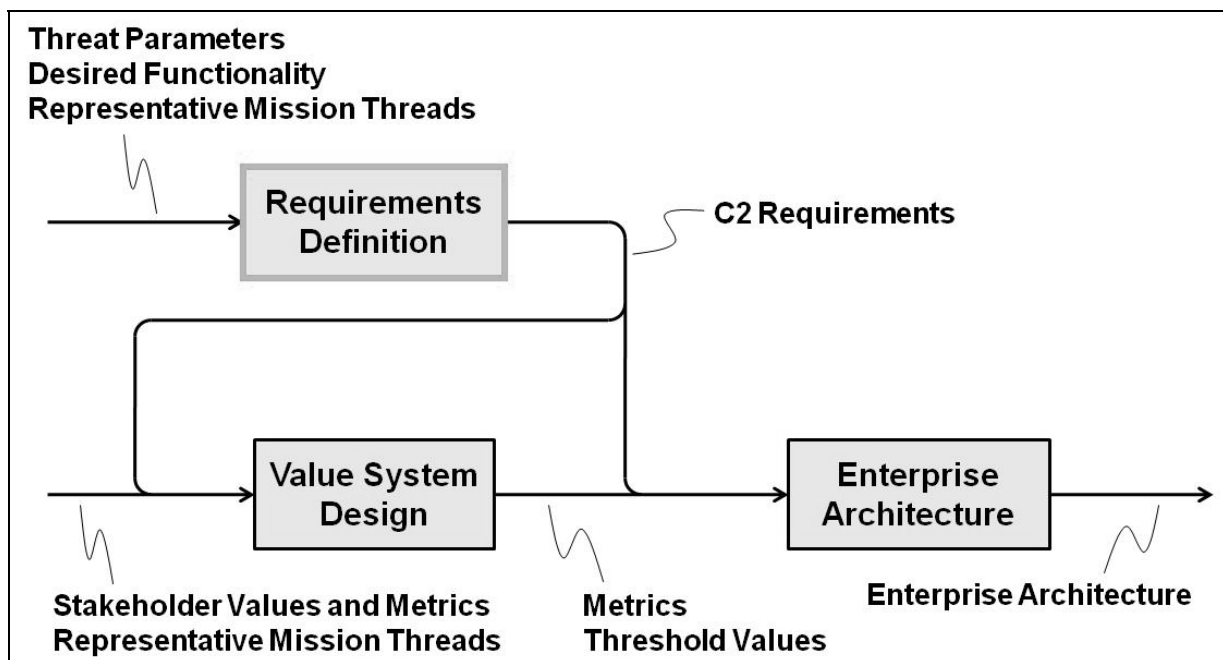
**Figure 4: Mission Thread Definition Task Relationships**

Doctrine identified during Stakeholder Analysis helped define context, functionality and relationships to create mission threads. The mission threads formed part of the basis for requirements development.

## 2. Functional Analysis Phase

### a. Requirements Definition

The purpose of the Requirements Definition stage of the project was to identify the functional requirements necessary to accomplish the SUW and MIO missions. The Stakeholder surveys conducted in the Needs Analysis phase, along with the mission threads, provided the initial direction for this stage. Once the broad mission functions were derived from the surveys and mission thread sequence diagrams, research of Navy and DoD doctrine and policy publications provided an additional level of detail for the requirements. This filled in some areas that had been unaddressed and expanded on those that were already addressed. The functional requirements subsequently populated a CORE model, described below, which was used to validate the adequacy of the function list. CORE is a commercially available systems engineering and design software tool. The requirements list was further expanded in the Value System Design stage by adding performance and constraint requirements that quantify the capability of a specific instantiation of the architecture. Figure 5 summarizes the relationship of the Requirements Definition task to the other tasks.



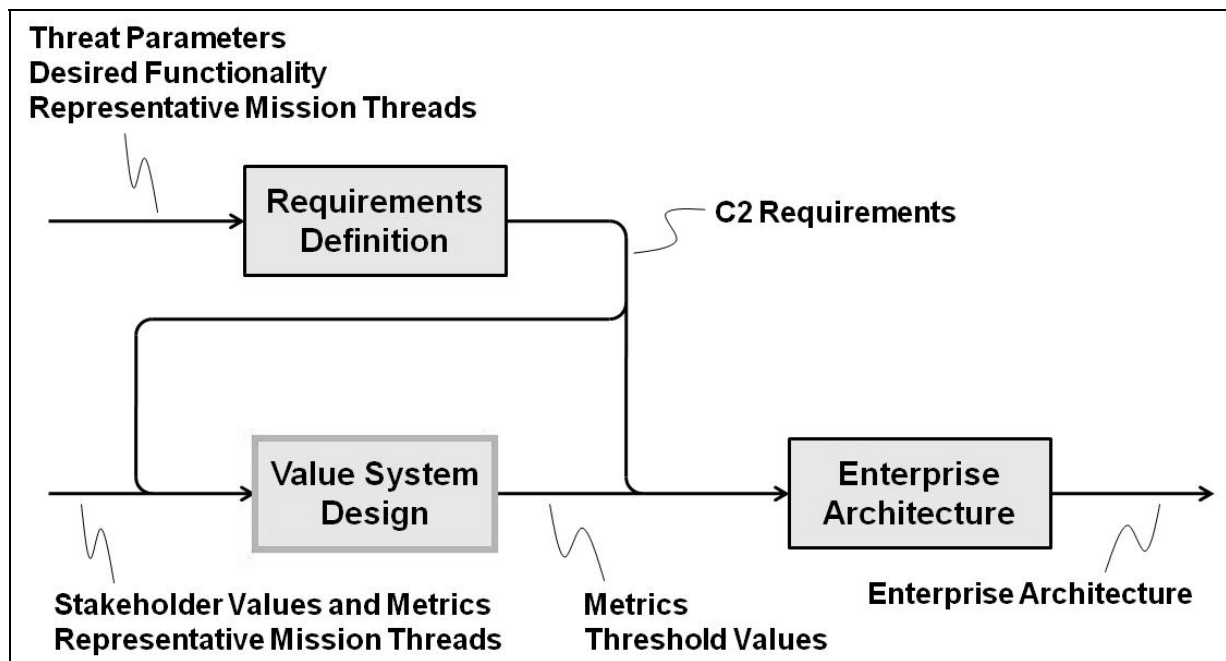
**Figure 5: Requirements Definition Task Relationships**

Information from the Needs Analysis phase and the Value System Design were used to develop the C2 requirements. The C2 requirements then become the foundation for the Architecture and also supported the Modeling and Analysis phase.



### ***b. Value System Design***

The objective of the Value System Design was to bridge together the stakeholder functional needs and the C2 requirements by using the mission threads and Navy Doctrine to formulate system objectives and develop threshold values. The Value System Design was also used to develop objectives and map those objectives to the stakeholder requirements through the use of associated values in the form of performance measures. Each requirement was then mapped to the function that it supported in order to provide full traceability between requirements and architecture functionality. Figure 6 summarizes the relationship of the Value System Design Task to the other tasks.



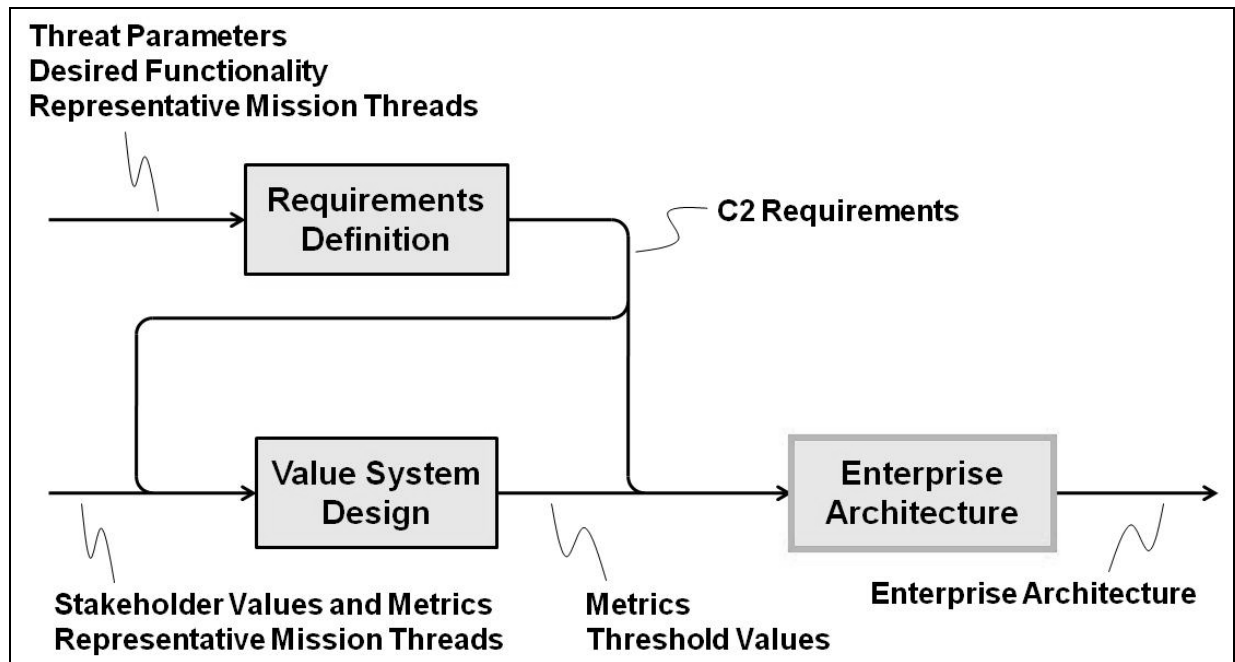
**Figure 6: Value System Design Task Relationships**

Information from the Needs Analysis phase and the Value System Design were used to develop the C2 requirements. The C2 requirements then become the foundation for the Architecture and also supported the Modeling and Analysis phase.

### ***c. Enterprise Architecture***

The Enterprise Architecture task defined the functionality of the C2 system and the C2 system's interfaces with other systems. The architecture was developed based on the C2 system requirements produced during the Requirements Definition task. As the architecture was

developed, the requirements were allocated to the C2 system functions. This ensured that the architecture addressed all of the C2 system requirements. Figure 7 summarizes the relationship of the Enterprise Architecture task to the other tasks.



**Figure 7: Enterprise Architecture Task Relationships**

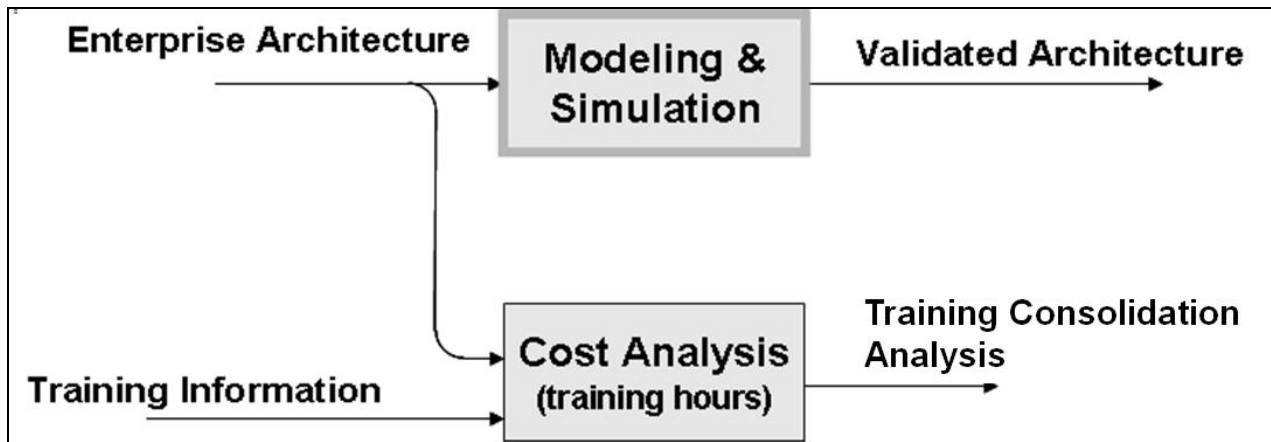
C2 Requirements described the capability of the system. The Enterprise Architecture task developed the architecture products.

### 3. Modeling and Analysis

#### *a. Modeling and Simulation*

The overall objective of the Modeling and Simulation (M&S) activities, seen in Figure 8, was to verify the architecture through the use of model-based systems engineering, an integral part of the requirements and architecture development process. M&S was used to verify and improve the operational and the functional activity models that were derived from the architecture and based on the requirements.

Verification was accomplished using two different, but complementary, M&S techniques: discrete event simulation and Colored Petri Nets (CPN). The purpose of this verification effort was to verify that the architecture was complete, internally consistent and executable. The discrete event simulation was also used to create a dynamic view of the OV-5 and SV-4.

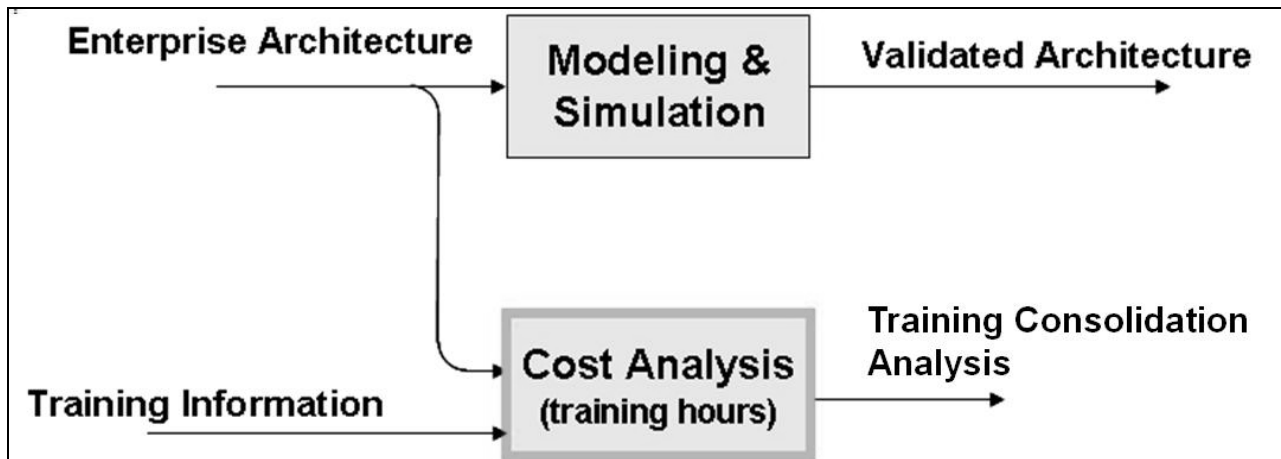


**Figure 8: Modeling and Simulation Task Relationships**

C2 Requirements described the capability of the system. The Enterprise Architecture task developed the architecture products.

### ***b. Cost Analysis***

The Cost Analysis task was conducted in parallel with M&S and was the culminating activity for the entire project. Activities in the prior phases were conducted to provide input (in the form of the architecture products) into the Cost Analysis task. The Cost Analysis task investigated multiple means of establishing a quantitative measure of cost comparison, ultimately using school house training hours as the metric. The architecture functionality was compared with available training information from two combat system training courses to investigate if a common architecture could result in lifecycle cost savings (measured in terms of training hours). Figure 9 summarizes the relationship of the Cost Analysis task to the other tasks.



**Figure 9: Cost Analysis Task Relationships**

Training Information and the Enterprise Architecture are used to estimate potential savings (measured in training hours) that could be achieved by using a common set of C2 requirements.

#### **D. ASSUMPTIONS**

When using the term command and control, the project makes no distinction between the human, hardware, software, and procedural elements of the system. The project identifies the functionality of command and control as it applies to the two mission threads. The project does not further decompose the functions to a physical architecture where distinctions between human, hardware and software actions would become more evident. In other words, the scope of the project ends at defining C2 functionality, and does not identify the components and procedures necessary to achieve the functionality. This activity is left to the trade space for follow-on efforts.

The project acknowledges that the requirements and architecture do not represent a complete set of C2 functionality. Project resource constraints were prohibitive in producing a comprehensive C2 architecture and requirements set. However, the project does demonstrate a process for developing common requirements and architecture, and then using the architecture to identify potential areas of cost savings. It is the expectation of the project team that this process will provide valuable insight, and will be scalable, for developmental efforts for actual systems. It is also expected that the requirements and architecture products produced by this project will provide a baseline for future development efforts.

## **II. NEEDS ANALYSIS**

The System Engineering Process began with the Needs Analysis phase. The given problem statement was refined to further understand the needs and expectations of the stakeholders. In this phase the mission threads were researched and more clearly defined as part of the project proposal. The threats against which the C2 architecture and requirements must perform were also identified. These tasks occurred in parallel.

### **A. STAKEHOLDER ANALYSIS**

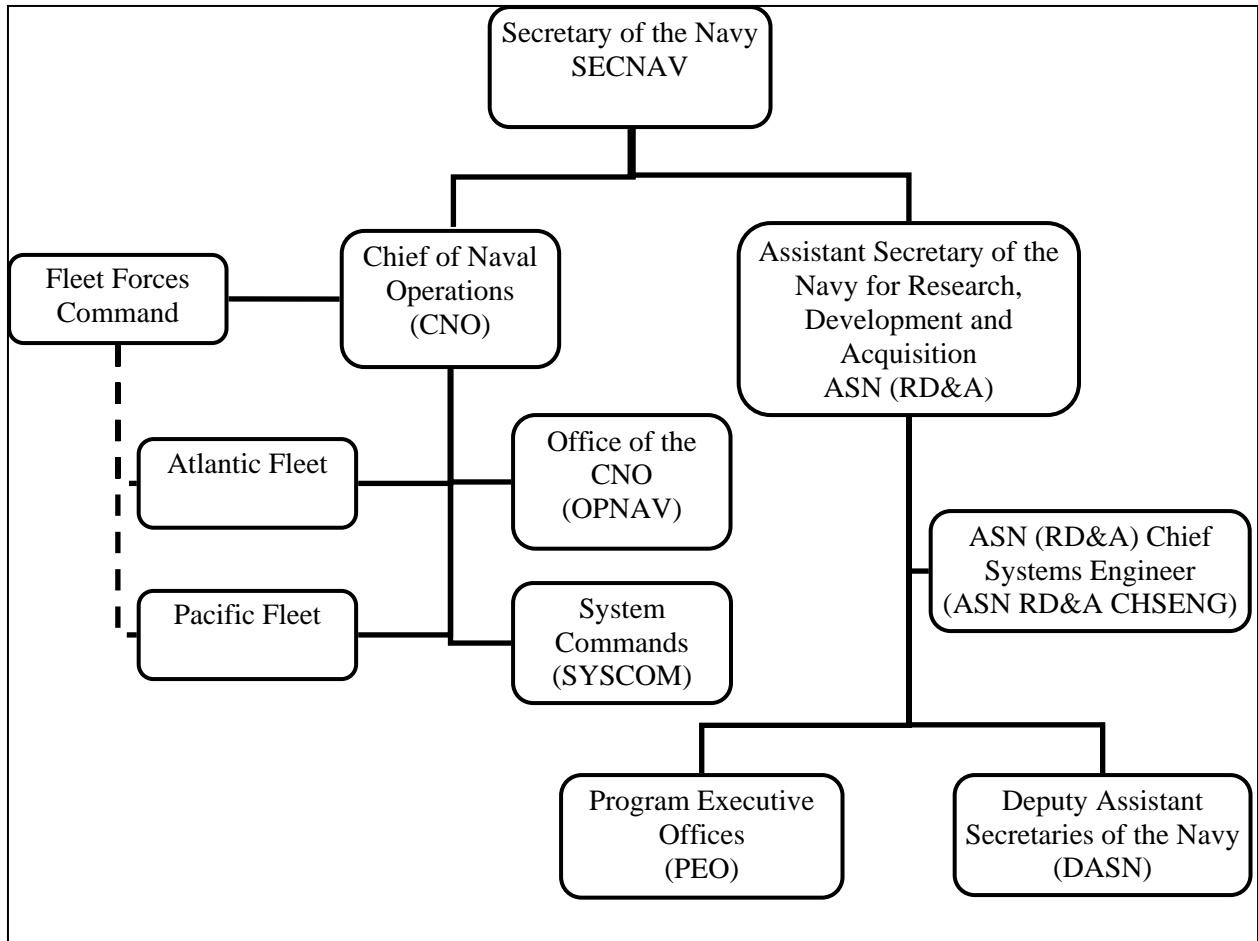
#### **1. Background**

The objectives of the stakeholder analysis were to identify the key organizations that can affect or will be affected by the development of the ship C2 system and also to identify stakeholder objectives and requirements. Stakeholders included interested parties such as future users, system developers, and resource sponsors.

The output of the stakeholder analysis was a summary of the key stakeholder needs and objectives identified from stakeholders and their documents. The stakeholder needs and objectives served to frame the requirements definition, enterprise architecture and value system design tasks during the functional analysis phase and ensured that the resulting products would satisfy the stakeholders.

#### **2. Stakeholders**

A full range of stakeholders were identified by considering the operational fleet organizations and the decision authorities of the three components of the DoD system life-cycle processes: the Joint Capabilities Integration and Development System (JCIDS), the Defense Acquisition System (DAS) and the Planning, Programming, Budgeting, and Execution System (PPBES). Figure 10 depicts the stakeholder organizations identified and their organizational relationships. Further details on specific organizations that were identified are provided in Table 1.



**Figure 10: Stakeholder Organizational Relationships**

These are the organizations identified by the project as stakeholders. Figure 10 indicates the organizational relationship between these organizations. The dashed line represents the coordination and support role that Fleet Forces Command provides to sustain the fleet.

**Table 1: Stakeholder Organizations and Roles**

This table identifies the organizations and describes the roles of the stakeholder organizations identified for this project. [From Department of the Navy, Research, Development and Acquisition, “ASN RDA”, 2009; Navy.mil, “The Operating Forces”, 2009; Navy.mil, “The Secretary of the Navy”, 2009; Navy.mil, “The Shore Establishment”, 2009].

<b>Organization</b>	<b>Role</b>
<b>Secretary of the Navy (SECNAV)</b>	Responsible for all affairs of the U.S. Navy.
<b>Office of the Chief of Naval Operations (OPNAV)</b>	Executes the Joint Capabilities Integration and Development System and Planning, Programming, Budgeting, and Execution System, defining requirements and budgeting for U.S. Navy systems.
N85 (Director, Expeditionary Warfare)	
N86 (Director, Surface Warfare)	
N88 (Director, Air Warfare)	
N6F (Director, Warfare Integration)	
<b>Fleet Force Command</b>	Trains, equips and mans the fleet.
Atlantic Fleet	
Pacific Fleet	
<b>Assistant Secretary of the Navy for Research, Development &amp; Acquisition (ASN (RD&amp;A))</b>	U.S. Navy decision authority in the Defense Acquisition System.
Chief Systems Engineer (CHSENG)	Provides overall Systems Engineering guidance to Navy acquisition.
<b>System Commands</b>	Provide engineering personnel under a matrix arrangement with the PEOs.
Naval Sea Systems Command (NAVSEA)	
Naval Air Systems Command (NAVAIR)	
Space and Naval Warfare Systems Command (SPAWAR)	
<b>Program Executive Offices</b>	Responsible for execution of the Defense Acquisition System.
Ships	
Carriers	
Integrated Warfare Systems (IWS)	
Command, Control, Computers, Communication, and Intelligence (C4I)	
Unmanned Aviation and Strike Weapons (U&W)	
Littoral and Mine Warfare (LMW)	
<b>Deputy Assistant Secretaries of the Navy (DASN)</b>	Oversee major U.S. Navy acquisition programs for ASN (RD&A).
Ships/IWS	
Air	
C4I & Space	

Several stakeholders were identified to support this project execution. These stakeholders have worked, or are currently working, in the C2 requirements and architecture areas. They have provided valuable input to the project throughout the process. These stakeholders are listed below in Table 2.

**Table 2: Project Stakeholders**

This is a list of the identified stakeholders who were able to participate in the project. These stakeholders acted as advisors and provided input and guidance to the project team.

<b>Name</b>	<b>Organization</b>	<b>Job Description</b>
Marc Stockbauer	OPNAV N864	Science and Technology Advisor for the Maritime Warfare/Surface Strike Branch (N864). Represents N864 interests in the approval and execution of ongoing and proposed Future Naval Capabilities (FNC), Joint Capability Technology Demonstrations (JCTD), Rapid Technology Transitions (RTT), Rapid Development and Deployment (RDD) and Defense Advanced Research Projects Agency (DARPA) efforts.
Gil Goddin	Naval Surface Warfare Center, Dahlgren	Senior Systems Engineer in the Warfare Systems Department, Warfare Systems Engineering and Analysis Division and serves as Warfare Systems Definition Branch head. Serves as the enterprise Systems Engineer who works with Program Executive Office (PEO) Integrated Warfare Systems (IWS) to define commonality across platforms for combat system design.
Tim Neel	Naval Surface Warfare Center, Dahlgren	Senior Combat Control Systems Engineer in the Warfare Systems Department, Combat Control Division. Develops advanced C2 architectures for Surface Navy Combat Systems.
Doug Haas	Naval Surface Warfare Center, Dahlgren	Senior Technical Advisor to the Warfare Systems Department, Combat Control Division. Supports the department for combat control systems engineering matters regarding the continued advanced development of surface combatants.



### 3. Methodology

The stakeholder analysis consisted of an evaluation of both Joint and Navy guidance and doctrine. Interviews with stakeholders helped to identify the objectives and development considerations that drove the architecture and requirements of the ship C2 system. In the evaluation of stakeholder documents, a full range of guidance was considered, from overarching maritime policy to surface warfare tactics, techniques, and procedures (TTP). The documents used in this analysis included U.S. Naval guidance, the Joint Functional Concepts (JFC) and Joint Integrating Concepts (JIC) from the Joint Chiefs of Staff and U.S. Naval doctrine, which are listed in Table 3. U.S. Naval guidance defines the missions the U.S. Navy performs and key characteristics of U.S. Navy performance. The JFC define the functional capabilities of the joint force while the JIC define tasks, conditions, and standards [Chairman of the Joint Chiefs of Staff 3010.01B, 2006]. U.S. Naval doctrine defines how the U.S. Navy conducts its missions, specifically how C2 is executed within the Surface Warfare and Maritime Interception Operations missions.

**Table 3: Stakeholder Analysis Document List**

This is a list of the Joint and Navy publications that were researched for this project. Information gathered from these documents shaped the requirements and architecture development efforts.

“A Cooperative Strategy for 21st Century Seapower” [United States Navy/United States Coast Guard, 2007]
“Naval Operations Concept” [United States Navy/United States Marine Corps, 2006]
“Joint Command and Control Functional Concept” [United States Department of Defense, 2004]
“Functional Concept for Battlespace Awareness” [United States Department of Defense, 2003]
“Command and Control Joint Integrating Concept” [United States Department of Defense, 2005]
“Universal Naval Task List” [Chief of Naval Operations, 2007]
“Navy Surface Warfare Manual” [Office of the Chief of Naval Operations, 2007]
“Naval Doctrine for Military Operations Other-Than-War” [Office of the Chief of Naval Operations, 1998]
“Maritime Interception Operations” [United States Navy/United States Coast Guard, 2003]

The information gathered from the documents above was used to begin the requirements listing and was used to develop interview questions for the participating project

stakeholders. A common set of questions were presented to each of the stakeholder (reference Appendix B). The comments received were integrated with the main points from the guidance and doctrinal publications and are described in the following sections.

The results of this analysis were then divided into four sections: operational settings and threats; tasks and functionality; values and metrics; and acquisition guidance. Each section supported follow-on tasks in the Needs Analysis and the Requirements Analysis phases of the project. The stakeholder analysis also identified several items of information within the SUW and MIO TTPs that supported the mission thread and architecture development. These items included mission types, command organization and system interface requirements. To avoid duplication, these items were directly incorporated into the mission thread and architecture sections.

#### **4. General Results**

##### ***a. Operational Settings and Threats***

National-level defense guidance defines the missions the U.S. Navy is expected to perform in the future as well as the key characteristics of U.S. Navy performance. “A Cooperative Strategy for 21st Century Seapower” defines the following missions for naval forces: forward presence, deterrence, sea control, power projection, and maritime security [United States Marine Corps/United States Navy/United States Coast Guard, 2007]. However, the Naval Operating Concept (NOC) cites that the geographic focus of these missions are changing to emerging areas such as Africa, South America and Indonesia, specifically the Strait of Malacca [United States Navy/United States Marine Corps, 2006]. The changing geographic focus is important since the worst-case environmental conditions the U.S. Navy may face, such as sea state, atmospheric conditions, clutter levels, will drive the requirements on the C2 system [Goddin, 2008].

Threats were divided into traditional and irregular threats. Traditional threats to naval platforms include a wide variety of weapons from surface combatants, submarines, aircraft and coastal defenses. Traditional weapons that may be employed against naval platforms include Anti-Ship Cruise Missiles (ASCM), air-to-surface missiles and bombs, mines, torpedoes, naval guns, and rocket projectiles [Office of the Chief of Naval Operations, 2007].

Irregular threats span from smaller craft and Unmanned Aerial Vehicles (UAVs) to catastrophic threats. Fast attack craft use crew-served weapons, rockets, ASCM, wake-homing torpedoes and water-borne Improvised Explosive Devices (IED) as a threat in littoral waters [Office of the Chief of Naval Operations, 2007]. The small boat threat is of specific concern, including craft as small as personal watercraft. This threat is further complicated in a high-clutter, high sea state operational environment [Goddin, 2008]. Aircraft, such as small planes and UAVs, submersibles, and commercial platforms pose potential harm. Criminal organizations and piracy have evolved with organized attacks and improved communications systems and weapons. Disruptive information technology, directed energy, and cyber terror also pose as threats to naval platforms. Catastrophic threats, namely Weapons of Mass Destruction (WMD) remain a threat as well [Office of the Chief of Naval Operations, 2007].

#### ***b. Tasks and Functionality***

The “Universal Naval Task List” (UNTL), Version 3.0 defines the tasks that the U.S. Navy performs. In particular, Chapter 3 defines the tactical-level tasks in the Navy Tactical Task List (NTTL). The NTTL was a useful tool to assess the range of tasks that the ship C2 system should be able to support. Four major Navy Tactical Tasks (NTA) were identified to scope the ship C2 system architecture:

- Conduct Counter-mobility (NTA 1.4),
- Perform Collection Operations and Management (NTA 2.2),
- Process Targets (NTA 3.1), and
- Acquire, Process, Communicate Information and Maintain Status (NTA 5.1) [Chief of Naval Operations, Commandant of the Marine Corps, 2007].

The tactical tasks are further decomposed in Table 4.

**Table 4: Navy Tactical Tasks**

These are the NTAs that were used as the outline to develop the requirements and architecture.

NTA	Description
1.4	<b>Conduct Counter-mobility:</b> “To construct obstacles and employ area denial efforts including mines to delay, disrupt, and destroy the enemy. The primary purpose of counter-mobility operations is to slow or divert the enemy, to increase time for target acquisition, and to increase weapons effectiveness.” [UNTL v 3.0: 3-B-16 – 3-B-20]
1.4.6	Conduct Maritime Interception
1.4.6.1	Conduct Visit
1.4.6.2	Conduct Search
1.4.6.3	Conduct Seizure
2.2	<b>Perform Collection Operations and Management:</b> “To gather data, information, and previously produced intelligence from all sources to satisfy the identified requirements.” [UNTL v 3.0: 3-B-33 – 3-B-35]
2.2.1	Collect Target Information
2.2.1.1	Detect Contacts
2.2.1.2	Track Contacts
2.2.1.3	Classify Contacts
2.2.1.4	Identify Contacts
2.2.1.5	Localize Contacts
3.1	<b>Process Targets:</b> “To positively identify and select land, sea, and air targets that decisively impact battles and engagements and match targets with appropriate firepower systems ...” [UNTL v 3.0: 3-B-44 – 3-B-45]
3.1.1	Request Attack
3.1.2	Select Target to Attack
3.1.3	Select Platform(s) and System(s) for Attack
3.1.4	Develop Order to Fire
3.1.5	Conduct Tactical Combat Assessment
5.1	<b>Acquire, Process, Communicate Information and Maintain Status:</b> “To obtain information on the mission, enemy forces, neutral/non-combatants, friendly forces, terrain, and weather. To translate that information into usable form and to retain and disseminate it.” [UNTL v 3.0: 3-B-91 – 3-B-94]
5.1.3	Maintain Information and Naval Force Status
5.1.3.1	Maintain and Display Tactical Picture
5.1.3.2	Maintain and Display Force Command and Coordination Status
5.1.3.3	Maintain and Display Units Readiness

The listing of Navy tactical tasks is limited to the detection, tracking, classification, identification, and reporting and boarding of surface threats as well as the detection, tracking, identification, and reporting of merchant ships during MIO. NTA (Navy Tactical level of war tasks) 1.4.6 addresses the conduct of Visit, Board, Search and Seizure (VBSS). NTA 2.2.1

covers the detection, tracking, classification and identification of contacts. NTA 3.1.1 includes C2 tasks associated with threat evaluation and weapons assignment. NTA 5.1.3 focuses on threat and status reporting.

The “Navy Surface Warfare Manual” defines a comparative set of top-level functions, termed the Surface Warfare kill chain, which was directly applicable to the project requirements and architecture development efforts. The components of that kill chain are: find, fix, track, target, engage, and assess [Office of the Chief of Naval Operations, 2007].<sup>1</sup>

- **Find:** Monitor environment
- **Fix:** Localize the potential target
- **Track:** Maintain continuous track
- **Target:** Check for Rules of Engagement (ROE) and coordination measures and match weapon and sensor to target
- **Engage:** Issue the engagement order and create effects on target
- **Assess:** Assess where desired effects were achieved, including physical and functional damage

Within the find, fix, and track phases, off-board platforms such as helicopters, UAVs and Unmanned Surface Vehicles (USV) play an extensive role to extend detection ranges. The integration of those sensors into the tactical picture may be considered a key factor [Haas and Neel, 2008]. Also, Chemical, Biological and Nuclear (CBN) sensors, either shipboard or on UAV or USV, play a role in identifying standoff ranges for threats [Stockbauer, 2008].

Within the target phase of the kill chain, the principles of preplanned responses have significant impacts for the ship C2 system. “Preplanned responses will be executed for all critical and unknown surface contacts that may enter into the SUW AO as established by the strike group commander” [Office of the Chief of Naval Operations, 2007]. This implies that there is a requirement for the ship C2 system to be able to provide automated decision support based on preplanned responses to any and all surface contacts.

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<sup>1</sup>The project uses the kill chain terminology as defined by the Navy in “Navy Warfare Publication: Navy Surface Warfare Manual NWP 3-20”, which is consistent with the joint document NTTP 3-60.1 “MULTI-SERVICE TACTICS, TECHNIQUES, AND PROCEDURES FOR TARGETING TIME-SENSITIVE TARGETS”, dated April 2004. Other documents exist (e.g. the Capabilities Based Assessment Users Guide, December 2006, JCS J-8) which use slightly different terminology for the kill chain.

Part of preplanned responses, is support for automated identification. For surface contacts, this includes detection of a muzzle flash by an Electro-Optical/Infra-Red (EO/IR) sensor, range rings, Identification Friend or Foe (IFF) returns, or kinetic information. The next step is support for an auto-engage capability that can be configured and initiated by the operator [Haas and Neel, 2008].

The engage phase of the kill chain is not limited to kinetic effects. Non-kinetic effects are expected to have a growing influence in future SUW and MIO missions, especially against small boats. Potential non-kinetic effects included Radio Frequency (RF) weapons to disable engines and prop-fouling devices [Haas and Neel, 2008]. Non-damaging effects are a specific subset of non-kinetic effects for use in commercial and civilian maritime craft interdiction [Stockbauer, 2008].

Success in a SUW mission depends upon the ability to make better decisions faster than the enemy can react to them, known as decision superiority [Office of the Chief of Naval Operations, 2007]. Decision superiority consists of two elements, information superiority and knowledge superiority. Information superiority is defined as “the operational advantage derived from the ability to collect, process, disseminate, and display an uninterrupted flow of tactically and strategically relevant information while exploiting or denying an adversary’s ability to do the same” [Office of the Chief of Naval Operations, 2007, 1-8]. The Department of Defense Dictionary of Military and Associated Terms includes a similar definition of information superiority [Joint Staff, 2008]. Knowledge superiority is the advantage over the enemy in education, training, and experience [Office of the Chief of Naval Operations, 2007].

The ability to accurately identify friend, neutral, and hostile ships in a saturated environment is a major factor in decision superiority [Haas and Neel, 2008; Stockbauer, 2008; Goddin, 2008]. This involves the integration of all available sensor sources and Indications & Warnings (I&W) that support accurate determinations of identity that can be acted upon with high degrees of confidence. This includes the integration of EO/IR and acoustic data into the tactical picture. This high volume of data leads to the need for tailor-able tactical and operational pictures where the data displayed is driven by the mission requirements [Haas and Neel, 2008].

Other major concepts include Distributed Weapons Control, and Engage on Remote. Both concepts depend on real-time sensor netting. Real-time sensor netting is the sharing of

sensor data to ensure a common picture across platforms. Distributed Weapons Control includes the distributed coordination of engagements while Engage on Remote is the ability to engage targets using sensor data from another platform. The keys to Distributed Weapons Control, Engage on Remote and real-time sensor netting are time accuracy, navigation accuracy, and data registration [Haas and Neel, 2008].

Several key needs specific to the MIO mission were also identified during Stakeholder Analysis. Maintenance of the surface picture was an overarching element of MIO. Maintenance of the surface picture includes: accounting for all surface contacts by name, track number and MIO control contact number, maintaining query and boarding status of each surface contact, updating and maintaining the tactical data link, and promulgate surface situation reports (SITREPs) [United States Navy/United States Coast Guard, 2003].

The C2 system needs to be able to integrate intelligence data into the MIO tactical picture. The Maritime Intercept Commander (MIC) Intelligence Officer needs to have the ability to draw from data from several organizations and data sources that can be used to support the classification and identification of commercial vessels, including: Office of Naval Intelligence (ONI) Maritime Target Development Division National Maritime Intelligence Center, Office of Naval Intelligence Merchant Ship Characteristics Hidden Compartment Book, and Sealink Databases of Vessels Electronic Intelligence parameters correlated to known sanctions violators [United States Navy/United States Coast Guard, 2003].

The Automatic Identification System (AIS) resides on commercial and naval ships and broadcasts ship information in the Very High Frequency (VHF) maritime band. The AIS transponder broadcasts ship name, classification, call sign, registration number, course and speed, and the International Telecommunications Union Maritime Mobile Service Identity (MMSI) to other AIS-equipped ships [United States Coast Guard, 2008]. This ability enables AIS-equipped ships conducting MIO operations to correlate ship names with intelligence databases prior to first interrogation. Of course, AIS is a cooperative system, meaning that a vessel that does not want to be easily identified can disable its AIS broadcast system.

### *c. Values and Metrics*

A wide array of metrics applies to the ship C2 system. Common metrics include Operational Availability ( $A_o$ ) [Goddin, 2008] and required bandwidth [Stockbauer, 2008]. Operational availability is a measure of the degree to which one can expect a system to work properly when required. [Defense Acquisition University, 2005].

Other programs completed extensive work in the development of C2 related metrics. The Single Integrated Air Picture (SIAP) developed a suite of metrics relating to the common tactical and operating pictures that can be adapted to the surface picture [Stockbauer, 2008]. Key metrics from the SIAP Attributes [Single Integrated Air Picture System Engineering Task Force, 2003] that will serve as a basis for key C2 system performance requirements include:

- Clarity: (Ambiguous Tracks) The percentage of real world objects that have more than one track assigned. (Spurious Tracks) The percentage of tracks without a corresponding real world objects.
- Continuity: The number of track numbers assigned to each real world object.
- Identification Completeness: The percentage of tracked objects that are in an identified state.
- Identification Correctness: The percentage of tracked objects that have the correct identification.

### *d. Acquisition Guidance*

PEO IWS has developed a vision for the engineering of future surface navy combat systems. Much of the vision provided is directly applicable to the development of the C2 system architecture and requirements. The PEO IWS vision is based on three major principles: a componentized system architecture using open information standards; a system product line developed based on a common, objective architecture; and a decoupling of system development from platform development while still accommodating platform-specific needs [Benedict, 2008]. In line with this strategy, the stakeholders provided specific acquisition guidance that ensures the C2 system design will support the future engineering vision for surface navy combat systems.

For existing platforms, the C2 system should have no impact to Cruiser-Destroyer manning requirements and no adverse impact to physical C2 spaces [Stockbauer, 2008]. For



existing and new platforms, the C2 system must apply Modular Open Systems Architecture (MOSA) design principles [Under Secretary of Defense for Acquisition, Technology and Logistics, 2003; Stockbauer, 2008] and maintain independence of the C2 system application from the underlying Commercial-Off-The-Shelf (COTS) computing plant [Stockbauer, 2008]. A MOSA design is defined by key principles: use of a modular design, definition of key interfaces and use of open standards. A modular design involves the development of components that implement cohesive functionality, hide the inner workings of the component, limit impacts to other components and enable component reuse [Defense Acquisition University, 2009].

All of the standards employed by the ship C2 system must be consistent with the DoD Information Technology Standards Repository (DISR) as dictated by CJCS Instruction 6212.01, Interoperability and Supportability of Information Technology and National Security Systems [Stockbauer, 2008; Defense Acquisition University, 2009].

All life-cycle considerations need to be examined for the ship C2 system architecture. Specifically training, including training timelines, schoolhouse requirements, and cost must be considered during development [Stockbauer, 2008].

## **5. Stakeholders Analysis Conclusions**

The stakeholder analysis was conducted by surveying publications that ranged from U.S. Naval guidance to tactics, techniques and procedures and by interviewing the project stakeholders. Through analysis several key stakeholder needs and objectives were identified. These results were divided into operational settings and threats, tasks and functionality, values and metrics, and acquisition guidance. These needs and objectives were summarized and used to support subsequent tasks.

The stakeholder analysis identified a categorization of threats that served as the basis for the threat assessment. The threat categories included traditional threats to naval platforms: surface combatants, submarines, aircraft and coastal defenses. Threat weapons included ASCM, air-to-surface missiles and bombs, mines, torpedoes, naval guns, and rocket projectiles [Office of the Chief of Naval Operations, 2007]. The threat categories also included irregular threats such as: fast attack craft (FAC) and small boats, small planes and UAVs, submersibles, commercial platforms, criminal and piracy organizations, disruptive information technology, directed energy, cyber terror and WMD [Office of the Chief of Naval Operations, 2007; Goddin, 2008].

The stakeholder analysis also identified several key functional needs from the stakeholders. These needs are summarized in Table 5.

**Table 5: Stakeholder Functional Needs**

Table 5 summarizes the key function needs identified during the Stakeholder Analysis phase of the project.

<b>Stakeholder Functional Needs</b>
Support the entire SUW kill chain (find, fix, track, target, engage and assess) [Office of the Chief of Naval Operations, 2007]
Positively identify contacts using all available sensors [Goddin, 2008; Haas and Neel, 2008]
Integrate off-board sensors into the tactical picture [Haas and Neel, 2008]
Support automated identification (e.g. detection of muzzle flashes with an EO/IR sensor, range rings, IFF returns or kinetic information) [Haas and Neel, 2008]
Support distributed weapons control and real-time sensor netting [Haas and Neel, 2008]
Support pre-planned responses (PPR) [Office of the Chief of Naval Operations, 2007]
Employ non-kinetic and non-damaging effects [Stockbauer, 2008]
Maintain the MIO picture, including query and boarding status, track reporting and SITREPs [United States Navy/United States Coast Guard, 2003]
Integrate intelligence data into the MIO tactical picture [United States Navy/United States Coast Guard, 2003]
Integrate AIS data into MIO contact classification and identification [United States Coast Guard, 2008]

The overarching stakeholder objective was decision superiority. This translated into metrics needed to assess the accuracy and speed with which the C2 system would distinguish between neutral and hostile contacts in a saturated environment, including track picture clarity, continuity, identification completeness and identification correctness [Haas and Neel, 2008; Goddin, 2008; Single Integrated Air Picture System Engineering Task Force, 2003]. Required values will be addressed in Section III.A of this report.

The stakeholder analysis was also used to elicit specific guidance on the acquisition of the ship C2 system. This guidance was used to drive the development of the C2 system architecture. Specific guidance on the C2 system architecture included: no impact to manning; must use a MOSA design; and must minimize life-cycle impacts.

## **B. MISSION THREADS ANALYSIS**

### **1. Background**

A mission thread is a descriptive process that entails what actions the systems must perform in a specified area of operation and includes the people, hardware, and software that are involved in performing these missions. Mission threads are generally derived from existing doctrine, such as the Naval Task List and stakeholder needs and wants that suggest several missions that a task force or battle group system should perform. The mission thread analysis utilized the doctrine identified in the Stakeholder Analysis as input to the mission thread definition.

Mission threads were needed for several reasons: identifying system functionality, identifying a reasonable operational environment in which the system would be expected to perform, and defining system boundaries. In addition, mission thread analysis facilitated in generating C2 requirements for the project. It should be noted that for both SUW and MIO mission threads, C2 includes functionality that would be assigned to shipboard personnel, hardware and software required to perform the mission. The outputs of the mission threads analysis included boundaries, high level interface definition, and functionality required to meet the stakeholder needs identified in the Needs Analysis phase of the project.

### **2. Methodology**

A mission threads analysis was performed to further define the threads identified in the project proposal. The threads aided in the development of the C2 architecture and requirements. A representative operational scenario was identified to demonstrate the functionality that a C2 Architecture would be expected to perform to support the mission. The inputs from the stakeholder analysis, navy doctrine, and publications were then organized into a scenario and event sequence that was consistent with existing doctrine. The threads include a text description of the scenario and an activity diagram depicting the operational nodes and the functionality conducted to complete the mission. The operational nodes are represented as column headers, and the activities performed by each node are represented by the graphics in each column. Both threads, SUW and MIO, have an operational node labeled “Command and Control” which represents the functionality of the project C2 system. All activities in the “Command and

Control” column (swim lane) are considered part of the C2 system. All other activities are necessary to complete the mission, but are considered outside the boundary of the C2 System functionality.

The mission threads analysis confines the multiple and diverse missions roles that a C2 architecture should be capable of and focuses the analysis and boundaries of the project on two particular mission threads that are diverse enough, yet stress C2 system interfaces to simulate operating in a real world environment. Furthermore, the threads were used in the development of the OV-1s and C2 requirements. Upon further input from the threat assessment, the mission threads were refined to support the requirements and architecture defined in later sections.

### **3. Surface Warfare**

#### ***a. Overview***

The Surface Warfare (SUW) mission thread depicts a surface warfare activity, focused particularly on the C2 system aboard a Navy combatant platform while executing the SUW kill chain process [Office of the Chief of Naval Operations, 2007] in open ocean operations. The thread is divided into three “swim lanes”: Sensor Systems, C2, and Engagement Systems. This thread focused on the C2 functions, processes, and interfaces required in supporting the mission.

#### ***b. Scenario Baseline Description***

A surface action group (SAG) [Office of the Chief of Naval Operations, 2007] consists of two guided missile destroyers (DDG) and one guided missile frigate (FFG) defending the maritime maneuver area in the Indian Ocean. All ships have Condition III watch stations manned. Condition III is defined as a wartime steaming with at least half of the systems at a ready status at all times [Cutler, 2008]. Each destroyer has one embarked helicopter to support over-the-horizon (OTH) search and targeting capabilities. The purpose of the maritime maneuver area defense operations, as has been seen in traditional roles, is to protect the friendly sea line of communication (SLOC) by preventing enemy combatants from operating in the area [Office of the Chief of Naval Operations, 2007]. Figure 11 is an operational view (OV-1) depicting the interfaces between the various naval platforms involved in the scenario. The

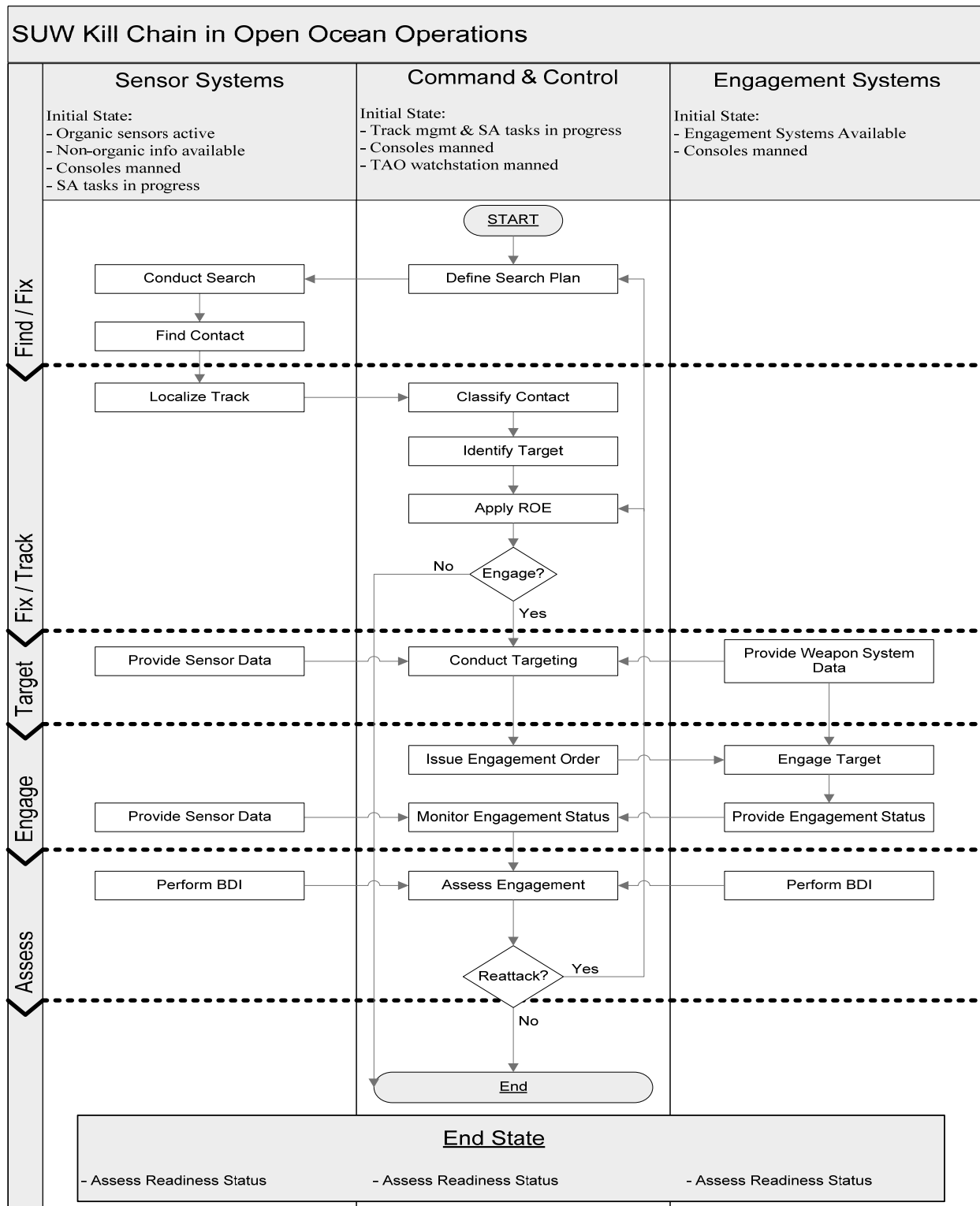
activity diagram (Figure 12) focuses in on the specific C2 activities that are performed by the C2 system aboard a single ship.



**Figure 11: Operational View: Surface Warfare**

This Operational View provides a high level depiction of the operational environment in which the SUW scenario is conducted.

The engagement systems and C2 functionality depicted in Figure 12 are organic to one DDG. The Sensor System swim lane represents organic and non-organic sensors. The remaining DDG and FFG in the SAG serve as non-organic sensor platforms for the purposes of this thread. A hostile combatant is operating in the area. The scenario is divided into five kill chain phases.



**Figure 12: SUW Kill Chain Mission Thread**

The SUW activity diagram applies the kill chain to an SUW scenario. The focus of this diagram is the Command and Control swim lane, which is used to identify and bound C2 functionality.

Within the 'Find/Fix' phase the C2 system defines the search plan and promulgates it to the Sensor Systems. The search will either be directed or area [Office of the Chief of Naval Operations, 2007]. The sensors conduct the search and find a surface contact.

The Sensor Systems then localizes the track and provides track information to C2system in the 'Fix/Track' phase. Using all available information, the C2 classifies the track as a combatant and reports tracking information to other surface platforms and up the chain of command, and identifies it as hostile [Office of the Chief of Naval Operations, 2007]. C2 applies Rules of Engagement and decides to engage the track.

In the 'Target' phase the C2 system considers sensor and weapon system information to conduct targeting. Targeting includes consideration of factors such as: desired effects, available options, deconfliction, weapons target pairing, threat defense capabilities and environmental factors [Office of the Chief of Naval Operations, 2007].

The C2 system then sends an engagement order to the Engagement Systems to conduct the engagement during the 'Engage' phase. C2 monitors the status of the engagement via inputs from the Sensor and Engagement Systems.

Finally in the 'Assess' phase C2 receives battle damage indicators from the Sensor and Engagement Systems and performs a battle damage assessment. Based upon the battle damage assessment, C2 will decide if the target needs to be reengaged. If the target does not need to be reengaged, the kill chain is complete and all systems assess readiness status.

### *c. Scenario Exceptions*

There are three exceptions associated with this thread. Exceptions are "alternative endings" to the baseline scenario. The baseline scenario describes one course of decisions and actions. Exceptions explore alternative actions and decisions that may occur throughout the scenario. Exceptions cannot address every possible alternative scenario, but they do try to capture common alternatives to the baseline.

The first exception is the possibility that the target is not to be engaged. C2 decides not to engage the contact based upon parameters such as classification and identification or ROE. The kill chain is interrupted, and the action is complete. All systems assess readiness status. Surface search is resumed based upon C2 direction [Office of the Chief of Naval Operations, 2007].

The second exception is the possibility for reengagement of the target due to a positive track. Battle damage assessment indicates that the target had not been eliminated [Office of the Chief of Naval Operations, 2007]. C2 decides to reengage. C2 still has a positive target classification and identification. C2 applies ROE and engages the target again in accordance with the baseline description.

The third exception is the possibility for reengagement of the target due to a lost track. Battle damage assessment indicates that the target had not been killed. C2 decides to reengage. The target track is lost. C2 identifies a search plan to regain the target track(s) and conducts the SUW kill chain in accordance with the baseline description [Office of the Chief of Naval Operations, 2007]. In order to limit the scope of the project due to time constraints single contacts were decided to be the focus of the SUW mission thread.

#### **4. Maritime Interception Operations**

##### ***a. Overview***

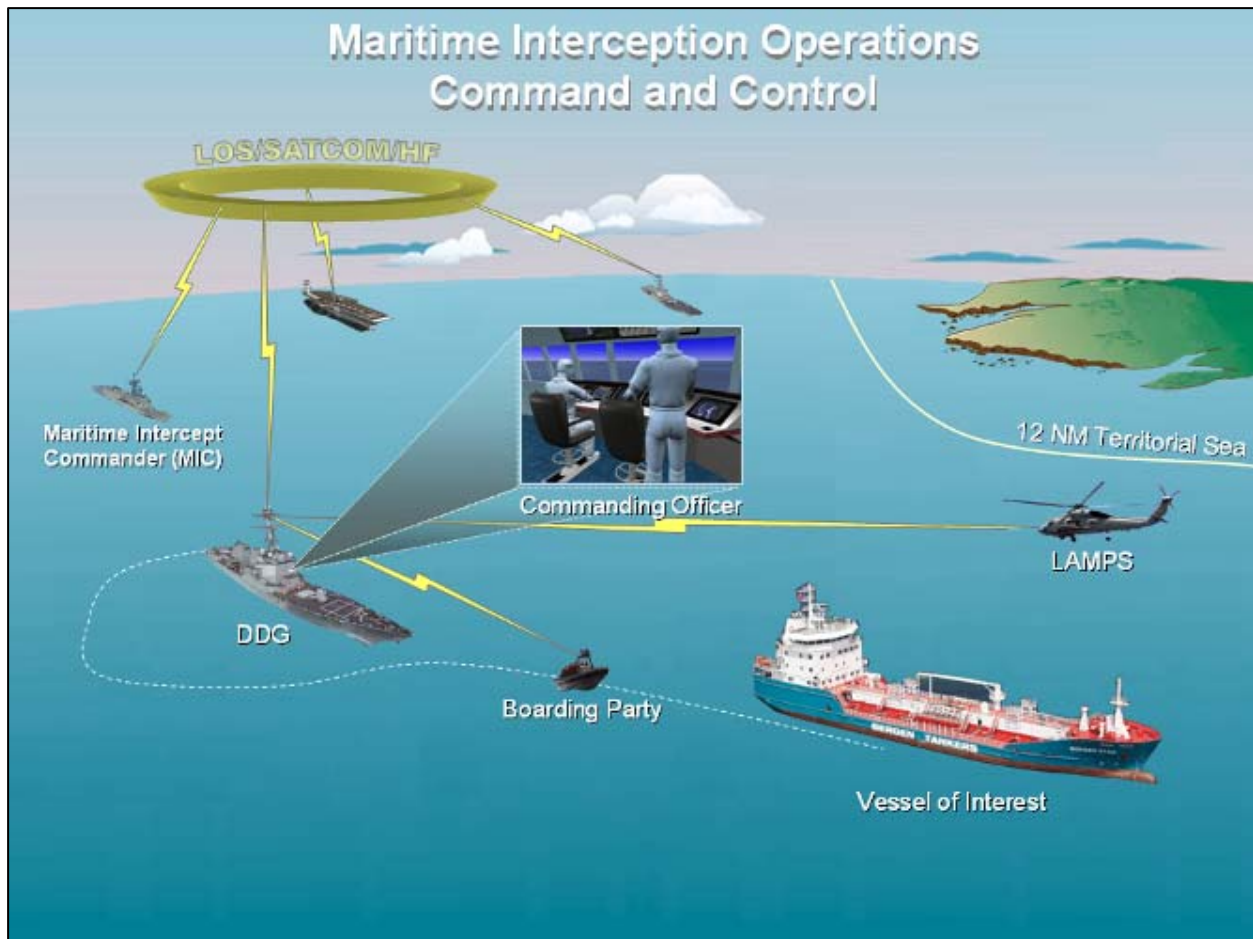
This thread particularly focuses on the use of C2 aboard a Navy combatant platform while performing Maritime Interception Operations in a peacetime environment. A high-level depiction of the operational environment (OV-1) is shown in Figure 13. The thread is divided into five swim lanes: Intelligence, Surveillance and Reconnaissance Systems; Maritime Intercept Commander; Organic C2: Organic Sensors; and Boarding Team. The thread focuses on the C2 functions, processes, and interfaces required to support the mission, see Figure 14. A distinct difference between the MIO mission thread and the SUW mission thread is the stronger reliance on Intelligence, Surveillance and Reconnaissance (ISR) assets and own ship sensor assets. In the SUW thread, a wider variety of sensor resources are available from accompanying ships. In the MIO thread, these external sensors are not available.

##### ***b. Baseline Description***

Deployed as part of a Carrier Strike Group (CSG), a DDG is operating independently to conduct MIO in the Indian Ocean, as shown in Figure 13. The DDG has Condition III (wartime steaming with at least half of the systems at a ready status at all times) watch stations manned. The DDG has one embarked helicopter to support MIO and OTH search capabilities. The DDG



operates within the littorals and maneuvers up to, but not within, 12 nautical miles of land [United States Navy/United States Marine Corps/United States Coast Guard, 2007]. The sensor systems, C2 functionality, and boarding team depicted are organic to the DDG. The ISR represented organic and non-organic ISR assets.

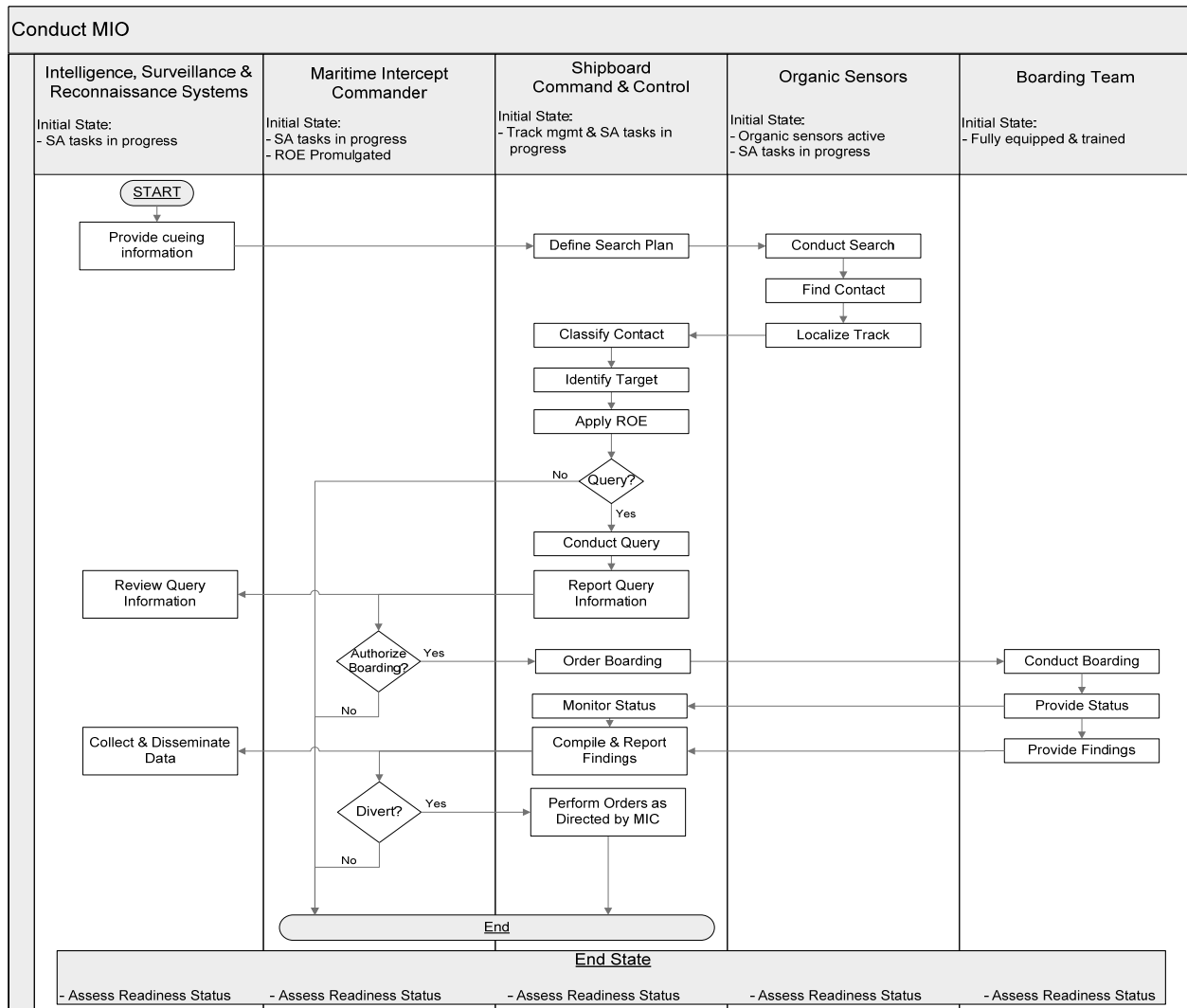


**Figure 13: Operational View: Maritime Intercept Operation**

The MIO OV-1 provides a high level depiction of the MIO operational environment.

### *c. MIO Chain of Events*

The following sequence of events describes the MIO scenario and the activities depicted in Figure 14. A vessel of interest is operating in the area.



**Figure 14: MIO Mission Thread**

The MIO activity diagram depicts the events that occur during the MIO scenario. The focus of this diagram is the Command and Control swim lane, which is used to identify and bound C2 functionality.

ISR assets notify C2 that a merchant vessel of interest is operating in the area [United States Navy/United States Coast Guard, 2003]. C2 defines the search plan and promulgates it to the sensor systems. The search is either a directed search pattern or area search pattern [Office of the Chief of Naval Operations, 2007].

The sensors conduct the search and find a surface contact. The sensors localize the track and provide track information to C2. Using all available information, C2 classifies the track as the merchant vessel of interest and identifies it as assumed friendly [Office of the Chief of Naval Operations, 2007]. C2 applies ROE as promulgated by the Maritime Intercept Commander

(MIC), and queries the merchant vessel [United States Navy/United States Coast Guard, 2003]. The DDG Commanding Officer (represented within the Command and Control swim lane) assumes duties as the On Scene Commander (OSC) [United States Navy/United States Coast Guard, 2003].

After the query is complete, C2 passes the query results to the MIC and to the ISR [United States Navy/United States Coast Guard, 2003]. The MIC evaluates the information and authorizes C2 to board the merchant vessel.

C2 directs the boarding party to board the merchant vessel [United States Navy/United States Coast Guard, 2003]. The boarding party provides status to C2 during the VBSS operation [United States Navy/United States Coast Guard, 2003]. C2 compiles the VBSS findings and forwards the information to ISR and MIC. MIC evaluates the information and directs C2 to divert the merchant vessel [United States Navy/United States Coast Guard, 2003]. The scenario is complete and all systems assess readiness status.

#### *d. Exceptions*

There are three exceptions associated with this thread. All three exceptions result in the termination of the MIO action. The first of these exceptions is the case of a ‘do not query’ order. C2 decides not to query the merchant vessel. based upon parameters such as classification and identification or ROE. The MIO action is terminated. All systems assess readiness status. Surface search is resumed based upon C2 direction [Office of the Chief of Naval Operations, 2007].

The second exception is the event of a ‘Do not board’ order. MIC does not authorize boarding of the merchant vessel. based upon parameters such as results of the query or ISR information. The MIO action is terminated. All systems assess readiness status. Surface search is resumed based upon C2 direction [Office of the Chief of Naval Operations, 2007].

The third exception is the event of a ‘Do not divert’ order. MIC does not authorize boarding the merchant vessel. based upon parameters such as results of the VBSS or ISR information. The MIO action is terminated. All systems assess readiness status. Surface search resumes based upon C2 direction [Office of the Chief of Naval Operations, 2007].

## **5. Mission Thread Analysis Conclusions**

The mission thread analysis produced two viable representative mission threads from the analysis of doctrinal requirements represented in the stakeholder analysis. The mission threads were a result of analyzing how the project proposal and problem statement could be represented to meet doctrine needs identified in the stakeholder analysis. In addition, the mission threads analysis scoped and bounded the project proposal to a manageable level to help by focusing system functionality. The mission threads also depicted the operating environment-situation (OV-1's) and the process flow to be used, as seen in Figure 14. Additionally, the mission threads facilitated the generation of the C2 requirements, which are addressed in the requirements definition section of this report.

## **C. THREAT ANALYSIS**

### **1. Background**

The threat analysis explored current and future threats to U.S. Navy platforms and their capabilities as background for the requirements definition and mission thread definition tasks. These threats and their capabilities were identified during the Stakeholder Analysis. Characteristics of the threats were used to support key C2 requirements, such as the requirement to integrate off-board sensors into the track picture. Thus, while the threat assessment did not define specific requirements, it provided information that was used to develop the C2 system requirements.

The "Navy Surface Warfare Manual," NWP 3-20, defines the categories of threats against U.S. naval platforms [Office of the Chief of Naval Operations, 2007]. Threats have evolved from conventional threats of surface combatants, submarines, and coastal defenses to a wide array of unconventional threats. These unconventional threats include FAC or patrol craft, small aircraft, UAVs, small submersibles, commercial platforms, piracy and crime, directed energy, cyber attacks, and WMDs [Office of the Chief of Naval Operations, 2007].

The threats against U.S. Navy ships have not remained constant. The geographic location of threats is changing from the blue water to littoral conflicts. Combined with the location, the threat has evolved from major naval adversaries to regional or coastal navies and non-state actors [United States Navy/United States Marine Corps, 2006].

Threats from other conventional navies cannot be excluded from analysis. China possesses a large number of guided missile boats, frigates, destroyers and submarines as well as a single aircraft carrier [Global Security.org, “Chinese Warships,” 2008]. Other significant navies exist, particularly India and Russia. India has multiple aircraft carriers and a large number of frigates, destroyers, corvettes, patrol craft, and submarines [Global Security.org, “Indian Navy,” 2008]. While declining in size, the Russian Navy still possess submarines, destroyers, frigates, corvettes and patrol craft [Global Security.org, “Russian Warships,” 2008]. Emerging conventional threats include small torpedo and ASCM boats [Stockbauer, 2008]. To maintain a manageable scope, the focus of the conventional threat assessment was maintained on China’s Navy, whose platforms are representative of the types of threats from a conventional navy.

The combination of insurgent and non-state actors using non-conventional weapons and conventional threats from other state navies poses a complex threat to U.S. Navy platforms. The conventional and unconventional threat sections detail some of the specific threat types that must be addressed in ship combat system requirements.

## **2. Methodology**

The threat assessment was conducted by surveying available public intelligence sources. This assessment was constrained to an unclassified level, and only open source intelligence was used. Sources included congressional testimony, third party information sources such as GlobalSecurity.org, and public reports from the DoD and the United Nations.

The threat categories were taken directly from NWP 3-20, the “Navy Surface Warfare Manual” (NSWM). The NSWM addresses all missions performed by U.S. Navy surface combatants, however, the mission threads were focused on the detection, tracking, classification, identification, reporting, and engagement or boarding of surface contacts. Thus, the threat assessment was limited to surface platforms, specifically, surface combatants, FAC, and commercial platforms, whose onboard systems and payloads could be used to threaten U.S. Navy ships.

### 3. Geographic Threat Regions

Just as the threats have expanded, so has the geographic focus of U.S. Navy operations. The U.S. Navy has broadened from blue-water, major ocean conflict with established navies to littoral conflicts with non-state actors. The emerging regions include Africa, South America and the Straits of Malacca [United States Navy/United States Marine Corps, 2006]. Hotspots in recent years include:

- **Nigeria (Niger Delta):** An unstable and impoverished region characterized by ethnic clashes, commercial sabotage, significant oil resources with little distribution of wealth, environmental damage, chronic poverty, and limited economic opportunities [Global Security.org, “Nigeria – Niger Delta,” 2008].
- **Colombia:** A 38-year civil war involving two leftist insurgent groups and a right-wing paramilitary organization, focused in the eastern lowlands and southern rainforest. The leftist and right-wing groups have allied with drug trafficking organizations and conducted numerous kidnappings to fund the insurgency [Global Security.org, “Colombia – Insurgency,” 2008].
- **Somalia:** No national government exists and fighting between clans and factions is violent and flares up quickly, especially in the south. U.S. and United Nations peacekeeping missions led to significant casualties and were withdrawn in the mid-1990s [Global Security.org, “Somalia Civil War,” 2008]. Piracy is also common in the area and will be addressed in detail later in the document.
- **Indonesia (Aceh):** An Islamic separatist movement has been fighting for an independent state since the 1970s. The Indonesian military has occupied the area since 1991, with substantial violence on both sides [Global Security.org, “Free Aceh (Aceh Merdeka),” 2008].

### 4. Conventional Threats: Surface Combatants

The Chinese People’s Liberation Army Navy (PLAN) surface combatant fleet in 2007 consisted of some 27 destroyers and 47 frigates, plus a large number of guided missile boats, torpedo boats and patrol boats. Chinese destroyers fall into seven classes, listed from oldest to newest: Luda, Luhu, Lihai, Luyang, Luyang II, Hangzhou and Luzhou. The Luda represents the

bulk of the current Chinese destroyer fleet. However, it is being phased out in favor of the Luyang II, Hangzhou and Luzhou-class destroyers [Global Security.org, “Chinese Warships,” 2008].

The threat assessment was focused on Hangzhou and Luzhou class destroyers, the two newest classes of destroyers. The Hangzhou class, pictured in Figure 15, is of interest because the Hangzhou class destroyers are Sovremenny-class destroyers purchased from the Russians. The Russian Sovremenny-class destroyers are considered to represent a more capable and balanced design than other Chinese warships. The Sovremenny-class destroyers carry the Top Plate D/E-band air search radar and the Palm Frond I-band surface search radar [Global Security.org, “Hangzhou Type 956 Specifications,” 2008]. The Sovremenny-class destroyers are equipped with SA-N-7 "Gadfly" or SA-N-17 "Grizzly" surface-to-air missiles (SAM). Both missiles are considered intermediate-range, with a range of 25 km [Global Security.org, “Hangzhou Type 956,” 2008]. Of more importance is that the Sovremenny-class destroyers carry the SS-N-22 Sunburn surface-to-surface missile. The Sunburn is a sea-skimming missile with a range of 161 km, a speed up to 4.5 mach and an active and passive radar seeker [Global Security.org, “Hangzhou Type 956 Specifications,” 2008]



**Figure 15: Haizhou Type 956 Destroyer**

Hangzhou Type 956 destroyers are a surface threat interest. They are Russian Sovremenny class destroyers capable of carrying the SS-N-22 surface-to-surface missile. [From GlobalSecurity.org, "Haizhou Type 956 Pictures," 2008]

The Luzhou class is the newest Chinese destroyer. The Luzhou class is designed primarily for anti-air warfare. Little technical data is publically available on this ship class. However, for the purposes of this threat assessment, it is considered less of a threat than the Hangzhou class described above [Global Security.org, "Type 51C Luzhou DDG-X," 2008].

Chinese frigates consist of four classes, listed from oldest to newest: Jianghu, Jiangwei I, Jiangwei II and Jiangkai. The Jianghu class is being phased out of the Chinese fleet with the new frigate construction focusing on the Jiangkai class, constituting all new frigate production [Global Security.org, "Chinese Warships," 2008].

The Jiankai class will possess a limited anti-air warfare and surface warfare capability. With the addition of Russian Kamov Ka-28 anti-submarine warfare helicopters and an active and passive sonar system, the mission of the class is primarily anti-submarine warfare. As a surface threat, the Jiankai class design uses stealth shaping, comparable to the French Lafayette-class frigates [Global Security.org, "Jiangkai Type 054 Frigate," 2008].



The threat to U.S. naval platforms is not limited to destroyers and frigates. The Houxin guided missile boats, which constitute the largest segment of China's missile boat fleet, carry the YJ-1 surface-to-surface missile [GlobalSecurity.org, "Houxin Class (Type 037-IG / Type 343M) large missile boats," 2008]. The YJ-1, also known as the C-801, is believed to be the result of reverse engineering of the Exocet missile. The missile has been demonstrated in tests to be able to sink a ship of 10,000 ton displacement and has a maximum effective range of 42 kilometers [GlobalSecurity.org, "C-801 YJ-1 / YJ-8 (Eagle Strike) / YJ-83 / CSS-N-4 SARDINE," 2008].

## **5. Unconventional Threats**

### ***a. Fast Attack Craft***

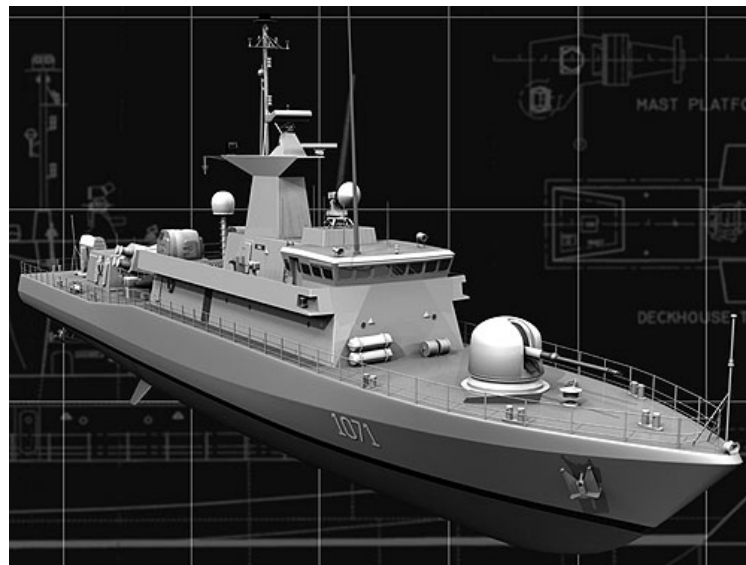
Of major focus in the category of unconventional threats are small boats. These craft can travel up to 40-50 knots, are armed with 50 caliber machine guns and Rocket Propelled Grenades (RPG) and possibly more advanced weapons, are manned by a crew of 2-3 or higher depending on size and have a low RCS [Haas and Neel, 2008]. Small boats can be divided into two categories: FAC and Fast Inshore Attack Craft (FIAC).

FAC are small military vessels used by countries with established navies for patrol, enforcement, search and rescue and coastal defense. They are fast, maneuverable, capable of operating in relatively shallow waters, have a relatively small radar signature and can carry a variety of lethal anti-ship armament. They are used by countries with large navies and extensive coastline as well as smaller countries with negligible other naval assets [Office of the Chief of Naval Operations, 2007]. Examples shown in Figure 16 and Figure 17 include the Super Dvora and Roussen Class FACs and provide a sense of the size and maneuverability of the FAC-type vessels.



**Figure 16: Super Dvora Fast Attack Craft**

The Super Dvora FAC is a small, highly maneuverable vessel well suited for operating in the littorals [From Office of the Chief of Naval Operations, 2007].



**Figure 17: Roussen Class Fast Attack Missile Craft**

The Roussen Class is another example of a FAC; highly effective in the littorals [Naval Technology.com].

FIAC are militarized commercial boats that are capable of limited operations in near-shore coastal areas. As the nautical equivalent of “technicals” (pickup trucks with machine gun mounts used ashore in many third world nations), these vessels are small-signature, fast, economical, and can be pressed into service on short notice in large numbers. FIAC size can be as small as a personal watercraft, can be open or enclosed, and have a small crew. These craft are often capable of operating at speeds over 30 knots. FIAC have limited sensors, weapons,

payload, and fuel. FIACs are hard to detect because they blend with the coastal environment and it is difficult to ascertain their intentions. They are usually unarmored and depend on speed and surprise. When used in a mass attack, the time to detect and identify a FIAC as hostile can permit enough time for the FIAC to get close and overwhelm a combatant's defenses [Office of the Chief of Naval Operations, 2007]. Figure 18 provides an example of an alleged Iranian FIAC, illustrating both the size and manning of the vessel.



**Figure 18: Alleged Iranian FIAC**

This alleged Iranian FIAC was filmed by the USS Hopper in the Strait of Hormuz, 6 Jan 2008. It appears to be a pleasure craft type vessel that is being used for military purposes [Karl and Martinez, 2008].

FAC and FIAC are well suited for coastal defense where the crews know the waters well and can take advantage of shallows and concealment areas to launch short-notice surprise attacks against hostile naval units. In this role they can take advantage of inlets and coastal clutter for concealment, and shore-based Command, Control and Communications (C3) and ISR networks for support and coordination [Office of the Chief of Naval Operations, 2007; Haas and Neel, 2008].

Defense against FAC and FIAC depends largely on an understanding of the threat, potential threat tactics, and own-force readiness. FAC are armed with a variety of conventional naval weapons including crew served and automatic naval canon and machine guns, surface-to-

surface missiles (SSM) and SAMs, torpedoes, RPGs and small arms [Office of the Chief of Naval Operations, 2007].

One of the most common RPGs is the Russian-made RPG-7, which has a maximum effective range of 500 meters for stationary targets and 300 meters for moving targets [GlobalSecurity.org, “RPG-7,” 2008]. However, the use of a RPG from a moving platform makes effective use difficult [Haas and Neel, 2008]. A 0.50-caliber machine gun has a longer effective range, up to 1,830 meters for the U.S. M2 “Ma Duce” [GlobalSecurity.org, “M2 .50 Caliber Machine Gun,” 2008]. However, employment from a moving ship will still require stabilization to be effective [Haas and Neel, 2008].

FIAC may be armed with a variety of weapons, from small arms and rocket propelled grenades, to anti-tank missiles and recoilless rifles. They can also be filled with explosives and used as waterborne IEDs either by remote control or with suicide crew [Office of the Chief of Naval Operations, 2007]. A platform smaller than a FIAC can also be employed as a Remotely Operated Vehicle (ROV). The ROV threat could include platforms as small as a jet ski [Haas and Neel, 2008].

It is important to note that the goal of an unconventional attack is not necessarily to sink the platform. One goal that can impact overall force effectiveness is to cause sufficient damage to reduce a ship’s operational capability. This will force the ship to remove itself from battle, likely while drawing protection from another friendly platform(s). For example the ship’s radar arrays may be targeted specifically to reduce operational capability [Haas and Neel, 2008].

### ***b. Commercial Platforms***

Commercial ships serve a wide variety of purposes and thus vary greatly in size and form from extremely large commercial carriers to small size fishing vessels. Commercial ships can pose a risk to U.S. Navy ships if used as an unconventional attack platform. The use of a legitimate commercial ship for an attack will make positive identification challenging prior to the moment of attack.

Lloyd’s Register classifies ships into the following categories: bulk carriers, container, cruise, gas, naval, ropax, tanker and yacht [Lloyd's Register, “Marine Ship Types,” 2008]. This analysis was focused on bulk carrier, tanker, container, and gas ships, as well as fishing vessels. Other types not discussed include tug, barge, and roll-on/roll-off ships.

Tanker and bulk carrier ships represent the largest portion of commercial deadweight tonnage, accounting for 36.9% and 36.0% respectively, of total commercial deadweight tonnage in 2006 [United Nations Conference on Trade and Development, 2006]. Tanker ships are designed to carry crude or refined oil products. Tanker ships range in capacity from 10,000 to 550,000 deadweight tons (dwt), divided into the types seen in Table 6 [Global Security.org, “Tanker Types,” 2008].

**Table 6: Commercial Platform Sizes**

These common commercial vessels have large cargo capacities and can be used as unconventional threats to naval combatant ships.

Class	Size (deadweight tons)
Handysize	10,000 – 30,000
Handymax	30,001 – 50,000
Panamax	50,001 – 80,000 (constrained by the locks of the Panama Canal)
Aframax	80,001 – 119,000
Suezmax	up to 150,000 (constrained by the Suez Canal)
Capesize	over 150,000 (must travel around Cape Horn or the Cape of Good Hope)
Very Large Crude Carrier (VLCC)	200,000 to 299,999
Ultra Large Crude Carrier (ULCC)	300,000 to 550,000

Aker Philadelphia Shipyard builds the Veteran Class MT46, a tanker ship with a length of 183 meters, a draft of 12.2 meters, a deadweight tonnage of 45,800 tons, a speed of 14.6 knots, a range of 14,000 nautical miles and a crew capacity of 32 [Aker Philadelphia Shipyard, “Veteran Class MT46 Product Tankers Data Sheet,” 2008].

Bulk carriers are designed to carry powders and grains that are stored in loose form. Cargo includes cement, grains and salt. Bulk carriers follow a similar type structure as tankers [Global Security.org, “Bulk Cargo Carrier,” 2008].

Container ships continue to grow in size and quantity, growing in total deadweight tonnage by 13.3 percent in 2006. The average capacity of container ships was 2,324 twenty-foot equivalent units (TEUs) in 2006. However, new classes of container ships have capacities of over 9,000 TEUs with Maersk Line producing a mega ship with a capacity of 13,640 TEU

[United Nations Conference on Trade and Development, 2006]. One specific example, Aker Philadelphia Shipyard produces the Philadelphia CV2600 class container ship, with a length of 217 meters, a draft of 12.5 meters, a deadweight tonnage of 29,400 tons, a speed of 22.5 knots, a range of over 10,000 nautical miles and a crew capacity of 26 [Aker Philadelphia Shipyard, “Philadelphia CV2600 Containership Data Sheet,” 2008].

Liquid Natural Gas (LNG) tankers are typically 259 meters in length and carry 120,000 cubic meters of LNG. Natural gas is liquefied at minus 160 degrees Celsius and is stored in insulated tanks on the ship [Global Security.org, “Tanker Types,” 2008]. The effects of a LNG explosion are not well known. Industry officials claim that any explosion would be confined to the tanker. However, the potential exists for clouds of natural gas to escape and lead to “back burn,” or gas cloud fires well away from the LNG ship [Daniel, 2004].

Fishing vessels vary greatly depending upon the location. In Somalia, illegal fishing is rampant due to the lack of government enforcement. Fishing vessels from a variety of countries, Belize, France, Honduras, Japan, Kenya, Korea, Pakistan, Saudi Arabia, Spain, Sri Lanka, Taiwan and Yemen, work off the coast of Somalia.

### *c. Criminal and Piracy Organizations*

Maritime piracy consists of any “illegal act of violence or detention committed for private ends against a ship, aircraft, or persons or property on board” a ship or aircraft “committed on the high seas” [Ameri and Shewchuk, 2008: 9]. Although the United Nations Convention on the Law of the Sea of 1982 distinguishes legally between piracy and robbery at sea, the two commonly are joined and many sources, including this summary, consider armed robbery at sea as one form of piracy [Ameri and Shewchuk, 2008].

Modern maritime piracy is an increasing threat to merchant and private vessels transiting or visiting certain regions of the world. Areas with widespread or severe poverty, failed governments and inadequate law enforcement have seen sharp increases in the number of reported incidents. Criminals in some areas have learned that it is possible to gain large rewards by robbing or ransoming undefended transient mariners. Governmental ineffectiveness or even complicity has propagated the trend. The International Maritime Bureau Piracy Reporting Center has reported “an unprecedented increase” in pirate activity for the first three quarters of 2008, with a total of 199 incidents. These incidents include 115 vessels boarded, 31 hijacked

and 23 fired upon. Five hundred eighty-one crewmembers were taken hostage, nine kidnapped, nine killed and seven missing and presumed dead. Almost a third of the incidents occurred in the waters near Somalia, with 12 vessels and 250 crew still held captive as of 30 September 2008. Nigeria was second in terms of numbers of reported incidents (24), mostly in the Lagos region, but a significant percentage of Nigerian incidents go unreported. Indonesia ranked third in numbers of attacks (23). Both Indonesia and the formerly hot Malacca Straits have both seen piracy decrease recently. Other persistent regions of activity include the Indian Ocean, Southeast Asia, and South America [ICC-Commercial Crime Services, 2008].

Other forms of criminal activity pose less of a threat to naval forces but still impact the course of United States naval operations. Sanction enforcement, counter-proliferation activities, protection of human rights (trafficking in persons), anti-drug operations, and counter-terrorist patrols each bring Navy personnel in contact with hostile forces with incentive and potential means to resist forcefully.

The modus operandi of pirate attacks includes covert boarding of anchored vessels at night, or pursuit in small boats and boarding with grappling hooks and ladders by day. Weapons can range from knives and machetes to military small arms and RPGs. A typical scenario after boarding includes robbing the crew and stripping the vessel of anything of value and, particularly around Somalia, kidnapping the crew, ship and cargo for ransom. Vessels attacked range from small private yachts to large container ships and bulk cargo carriers. Most pursuit attacks occur in daylight and at speeds averaging about 15 knots [Office of Naval Intelligence, 2008].

The threat to naval vessels is minimal when the pirates are unchallenged, but during enforcement activities the intercepting vessel can expect to be fired upon. On March 18, 2006 the USS Cape St. George's (CG 71) topsides sustained light damage from small arms fire while performing maritime security operations in international waters off the coast of Somalia. USS Gonzalez (DDG 66) and Cape St. George spotted and prepared to board a suspicious vessel towing two skiffs, when the suspected pirates opened fire with small arms. The Navy ships returned fire killing one suspect, burning the vessel to the waterline, and capturing the twelve surviving suspects [United States Naval Forces Central Command (NAVCENT) Public Affairs, 2008].

Threats expected from other forms of criminal activities, if any, would most likely be some form of resistance against boarding parties using individual weapons. However,

interdiction of a terrorist activity could result in a suicide ramming attempt or use of their vessel as a maritime delivered IED [Office of the Chief of Naval Operations, 2007].

## **6. Threat Signatures**

From the stakeholder analysis, a user need was identified to be able to classify and identify tracks using all available sensor sources. The possible threat signatures that can be used by the C2 system in support of classification and identification include radar, EO/IR, electronic support (ES) and acoustic. Each threat type will have the potential to have signatures that can be detected by the above sensor sources.

Radar Cross Section (RCS) data varies based on azimuth, radar frequency and Swerling case, but can be roughly quantified for the threats addressed above. The RCS for a small boat or FIAC will be on the order of  $0.02 \text{ m}^2$  [Payne, 2006]. One can reasonably expect that the RCS for a smaller size ROV will be even smaller. For surface combatants, including the guided missile boat and destroyer threats and commercial ships, the RCS is approximately equal to the displacement tonnage expressed in  $\text{m}^2$  [Payne, 2006]. For the Haizhou class destroyer, the RCS is approximately  $7,500 \text{ m}^2$ . For the Houxin class guided missile boat, the RCS is approximately  $500 \text{ m}^2$  [Payne, 2006].

The EO, IR, ES and acoustic signatures of different ships are unique and can only be discussed generally in this assessment. EO detection is a function of the environment and is based on the amount of visual contrast. The IR signature of a ship is driven by the exhaust points and the temperature contrast of the ship's exterior surfaces with its background, both of which are thermal sources. The ES signature of a ship is driven by the ship's RF emitters, including navigation radar, and communications systems. The acoustic signature of a ship consists of a mix of narrowband and broadband sources. Machinery is the primary narrowband acoustic source for a ship. Flow and cavitations are broadband acoustic sources and are a function of the ship's speed [Payne, 2006].



## **7. Threat Assessment Conclusions**

The threat assessment reviewed an array of threats, ranging from the FAC and FIAC threats to conventional naval combatants and commercial vessels. The threats facing U.S. Navy platforms include a wide range of threat sizes, speeds, threat systems capabilities and employment techniques.

The threat assessment identified five major types of threats from the above mentioned threat categories: ROV, small boats and FIAC, guided missile boats, destroyers and commercial vessels. The ROV threat is specifically treated as an IED. The small boat threat would be crewed and used in a coordinated, massed attack. Both threats present the same challenge of employment in constrained areas where the threat can use the environment and local ship traffic to screen intentions [Haas and Neel, 2008]. Commercial vessels present a threat primarily when they are utilized as a platform for attack or as an IED, similar to the ROV or FIAC threat but on a much larger scale [Office of the Chief of Naval Operations, 2007].

Conventional threats present similar challenges in that they can range greatly in size, from guided missile boats to destroyer-size platforms. However, the threat systems with the greatest range continue to be the ASCM, which will range in capability up to 160 kilometers [Global Security.org, “Hangzhou Type 956 Specifications,” 2008].

Table 7 summarizes some of the key characteristics of those threats and some of the specific challenges associated with the management of those threats.

**Table 7: Summary of Threat Parameters**

This table contains a summary of the threats and their related characteristics identified during the Threat Analysis.

Type	Size	Maximum Speed	Threat Systems & Range	Challenges
ROV	Comparable to jet-ski	40-50 kts	IED	Low RCS ; Blend in environment
Small Boat & FIAC	Comparable to recreational watercraft	40-50 kts	RPG: 300-500 m 50 cal: 1,830 m	Massed attack; Low RCS; Blend in environment
Guided Missile Boat (PLAN Houxin class)	62 m length 7.2 m beam	32 kts	YJ-1/C-801: 42 km	Small; extended range threat
Destroyer (PLAN Haizhou class)	156.4 m length 17.2 meters beam	32 kts	SS-N-22 Sunburn: 161 km	Multi-mission surface combatant
Commercial Vessel	Can be over 200 m	15-25 kts	RPG, 50 cal, IED	Difficult to identify

The information gathered during the threat assessment, including threat types, signatures, speeds, weapon systems and ranges, have some applicability to the definition of the C2 system requirements. The threat information summarized in Table 7 provided inputs to requirements development, which will be discussed in Section III.A. of this report. However, the specific threats and their parameters have more applicability to the definition of sensor and weapon system requirements for naval platforms. For example, the RCS of a personal watercraft does not affect the C2 system's required performance. The personal watercraft's RCS is of substantial import to the definition of sensor system requirements, which are outside the scope of this effort.

The threat assessment reinforces some key stakeholder requirements, including the need to integrate off-board sensors [Haas and Neel, 2008] and to utilize all available sensor data [Haas and Neel, 2008]. The over-the-horizon engagement ranges for enemy missile systems, such as the SS-N-22 and the YJ-1, highlight the need to utilize off-board sensors to extend the ship's detection range. The small RCS for FIAC and FAC vessels underline the need to exploit all available sensors to detect, classify, and identify the vessels as detections solely off radar data alone will be challenged by the small RCS.

### **III. FUNCTIONAL ANALYSIS**

Requirements and architecture products were produced in the Functional Analysis phase. Using the information gathered during the Needs Analysis phase, the value system design and requirements definition tasks developed the system requirements. The enterprise architecture then modeled the system functionality required to satisfy the requirements. Through this phase, previous tasks were revisited to determine if stakeholder inputs were needed for clarification, if mission threads were adequately defined, and if the threat assessment was fully established.

#### **A. REQUIREMENTS DEFINITION**

##### **1. Background**

The requirements definition task sought to translate stakeholder needs and objectives from the Needs Analysis phase into functional requirements descriptive of a C2 activity, and to allocate these requirements into a functional architecture capable of performing that activity. When possible, realistic or plausible operational constraints, measures of effectiveness, and measures of performance thresholds were identified and associated with those functions.

##### **2. Methodology**

The products of the preceding Needs Analysis phase, specifically the stakeholder analysis and mission thread definition were used as inputs to the requirements definition task. Unclassified Joint and Naval doctrine publications were researched to expand upon the guidance provided by the stakeholders about user needs, to provide context to the mission areas, and to provide insight into how the SUW and MIO mission areas would be performed. The derived C2 functions specific to the mission areas were initially compiled in a Dynamic Object-Oriented Requirements System (DOORS) database for configuration control and tracking purposes. DOORS is a commercially available requirements management software tool. This data was eventually migrated to a CORE file for commonality with the modeling tool intended to be used to validate the identified functions.

The output was a hierarchy of C2 functions with their associated requirements and metrics. These functions are listed in the table in Appendix C, “C2 Requirements, VSD and Architecture

Matrix” and described below. Traceability of those requirements to source doctrine publications was also recorded.

### **3. General Results**

A total of 77 functional requirements, 29 performance requirements and 12 constraints were derived from the stakeholder surveys and feedback, from the mission thread activity analysis, and from the doctrine publication research. Functional requirements describe what the system must be able to do. Performance requirements describe how well the system must perform. Constraint requirements describe other operational or design limitations with which the system must comply. The requirements address the command and control functions of surface warfare in general, such as maintaining surface situational awareness, evaluating contacts and developing engagement orders, plus the specific additional requirements necessary for the MIO mission, such as C2 support for conducting visits, boarding, searches and seizures, and for reporting. Throughout the process, it was discovered that detection, tracking, and reporting functionality was common for the MIO and SUW threads. Since many of the tactical picture requirements and evaluation needs are common to both combat and non-combat situations, the majority of the requirements make no distinction between MIO and SUW. This helped avoid generating a set of redundant requirements due to the artificiality of segmenting along mission lines.

The requirements are listed in Appendix C, along with the performance measures developed during the VSD stage. Table 8 illustrates a short excerpt of this appendix. Each requirement is tracked by number in a hierarchical arrangement in which higher level requirements are decomposed into multiple lower level requirements, as indicated by the number of decimal points in the requirement number. (Requirement 1.2 decomposed into 1.2.1, 1.2.2, etc.) Following each requirement statement is the source information for that requirement, and may be attributed to a Joint or Navy publication, a stakeholder, or another doctrinal source. Requirements that do not reference an external source were derived as necessary to ‘fill in’ the architecture when required. The Type column indicates whether a requirement is a functional or performance requirement, or a constraint. The Value System Design column further describes the requirement in terms of the intended objective and Measures of Performance or Effectiveness as described in the following section.

**Table 8: C2 Requirements and VSD**

This table contains a partial listing for illustration purposes. For full listing of the C2 requirements and VSD refer to Appendix C.

Requirement	Rationale	Type	Value System Design
<b>1.2 Collect Target Information</b> The C2 system shall collect target information for detecting, identifying, locating, and classifying targets.	NTA 2.2.1	Functional	Obj: Determine C2 capability of sensors to identify an object under varied noise, weather, terrain conditions  Performance Measure: Ability of sensors to identify an object under varied noise, weather, terrain conditions  Goal: Probability of detection and classification >99%
<b>1.2.1 Receive Sensor Inputs</b> The C2 system shall utilize radar, electro-optical/infrared (EO/IR), electronic surveillance (ES), identification friend-or-foe (IFF) and automatic identification system (AIS) data in the classification and identification of contacts.	Goddin, 2008; Haas & Neel, 2008	Functional	Obj: Assess C2 functionality in receiving data from sensors in detection, ID, and classification of contacts.  PERFORMANCE MEASURE: Ability of C2 to correctly and accurately detect, Identify, classify contacts from sensor data  Goal: Probability of correct detection, ID, and classification >85%

One of the lessons learned when the functions were evaluated for timing requirements against specific threats was that in the SUW role, the timing was either non-stressing or overly so, with little middle ground. Engagement timelines necessary to counter representative threats described in the Threat Analysis (Section II. C.) phase of this report were calculated, using the threat's expected detection range, closure rate and a mandatory safety range. These timelines, expressed in minutes or seconds, reflect the amount of time the ship had to detect and collect target information, process and engage the target, before it became vulnerable to enemy fire. A timeline allowance of zero seconds indicated a threat that was capable of launching a weapon against our ship at or beyond our ship's detection range of the enemy. Mandatory safety range was the maximum range at which the threat could launch a weapon against our ship. Detection range was a function of the height above the sea surface of the threat, which determined the range at which it would be detectable above the radar horizon in nominal RF propagation conditions. The parameters used in these calculations are shown in Table 7, "Summary of Threat Parameters." For example, in an encounter with a low capability surface platform that must close to within hundreds of yards or a mile of the ship, such as a FIAC, the ship had several minutes to

detect, assess, decide and act against the threat. However, against a peer-capability such as a missile armed destroyer capable of launching an ASCM from beyond the horizon, the capability of engaging in a surface warfare “shoot the archer” mode was essentially non-existent. The friendly ship must engage the ASCM in an air defense role, unless it can get a shot against the enemy vessel *several minutes before* the enemy can detect own ship and launch a missile. Thus, the SUW engagement timeline was typically either zero seconds against a missile ship or about 15 minutes against a FIAC/FAC.

This 15 minute timeline represented the time it would take a fast surface vessel to close the distance between the horizon and the ship assuming the ship does not contribute to or mitigate the threat’s rate of closure by high speed transit toward or away from the threat. This engagement timeline would be allocated across several of the performance measures listed in Appendix C, “C2 Requirements,” principally requirements 1.2 (Collect Target Information), 1.3 (Process Targets), and 1.4 (Localize Target), and their sub-elements. Although notional values were assigned to several of these performance measures, different allocations of time would be acceptable as long as the total timeline constraint is achieved. These measures collectively constitute the trade space.

## **B. VALUE SYSTEM DESIGN**

### **1. Background**

The Value System Design (VSD) is a hierarchy of objectives, functional requirements, Performance Measures (PMs), and their goals. Buede defines a VSD as a hierarchy of objectives that are important to the system’s stakeholders [Buede, 2000]. The VSD is a process and a product that identifies stakeholder objectives and ties them to requirements. The VSD results in a product that traces the objectives to the requirements and the development of PMs and their associated goals. These goals and metrics add value and meaning to what each functional requirement entails. In short the VSD is the bridge between the Needs Analysis and Functional Analysis by connecting the stakeholder’s objectives to the requirements definition phase.

## **2. Methodology**

The VSD effort was conducted in parallel with the requirements development. The VSD took the approach of identifying the objectives defined in the stakeholder analysis and mapping those objectives to respective functional requirements defined in the requirements definition. Performance and Constraint requirements were not the focus of the VSD, as these requirements identified in the Requirements Definition phase directly represent PMs and goals self-contained within these requirements. Although the VSD was not focused on the performance and constraint requirements, the VSD maintained the general hierarchy that was developed in the requirements definition. It is through the use of this hierarchy that the VSD was able to maintain configuration management in respect to the work done on the requirements definition. In addition, the VSD was able to determine several requirements that could be grouped within a single objective, which those groups of requirements could be addressed by one or two PMs and their respective goals.

PMs on the other hand were derived from a combination of mapping the objectives to the requirements and in addition from supplemental information derived from the Mission Threads and Threat Assessment. In short the VSD's PMs were pieces of information, values, and concepts taken from each of the respective sections discussed above. The PMs were identified to assess each requirement to determine how well they meet mission requirements, stakeholder objectives, and associated Navy doctrine and publications. It is through the interfacing of these sections together that the PMs could be derived. In other cases, PMs were directly taken from Navy Doctrine and Pubs.

The representative PM goals and values were based upon information from the stakeholder's analysis, Navy doctrine and publications, and the Navy Task List. In some cases, PM goals were not included in order to maintain the project at an unclassified level. In these cases the goals were derived for these particular PMs. The results of the VSD were organized into a tabular format to demonstrate how requirements fed into the stakeholder objectives and lastly how PMs were derived with their associated goals. The VSD alongside with the requirements can be found in Appendix C.

### **3. Conclusion**

A total of 77 functional requirements were identified in the requirements definition phase. Of those 77 requirements, 23 requirements were consolidated to support the same objectives, PMs, and goals. The remaining 54 functional requirements were addressed with distinct objectives, PMs, or derived values. What this means is that a majority of the requirements defined in the requirements definition phase had distinctive PMs and goals assigned to them and that these results could be traced back to the stakeholder objectives.

The VSD essentially provided evidence in mapping and tracing the stakeholders' objectives to the requirements and the requirements to the PMs and their associated values. The VSD validated and verified that the requirements definition phase captured the stakeholder objectives. In addition the VSD provided PMs and goals that can be utilized for further study.

## **C. ENTERPRISE ARCHITECTURE**

### **1. Background**

The enterprise architecture task defines the required behavior of the C2 system, the operational activities that the C2 system must support, and the functionality of the C2 system itself. The operational activities are based on current SUW and MIO doctrine identified during the Stakeholder Analysis task of the Needs Analysis phase. The operational activities reflect the tasks that must be completed in support of the missions identified in the Mission Thread Analysis, independent of their implementation in specific systems. The C2 system functionality defines what the C2 system is required to do and the interfaces with external systems that the C2 system must support. The enterprise architecture implements key inputs from the stakeholder analysis, namely the concepts of Distributed Weapons Coordination (DWC) and Engage on Remote (EOR).

DWC is implemented in the architecture through common algorithms for threat evaluation and engagement scheduling and the sharing of effectiveness data between platforms. In essence, each platform executes a common algorithm for threat evaluation. Based on the resultant common threat list, each platform exchanges engagement effectiveness estimates with other platforms. The engagement effectiveness inputs feed a common engagement scheduling algorithm, leading to common engagement assignments across the force.



EOR capability permits a ship to engage targets being tracked by other platforms, rather than solely those for which it has its own sensor data. Since each platform shares the same contact report inputs and the same tracking algorithms, this contributes to a common track picture between platforms. Once the common track picture has been developed, remote tracks and organic (own ship) tracks can be addressed on an equal basis, with no outward difference to the system operator. This permits the most capable and best situated sensor(s) and the most capable and situated weapons system to be utilized, even if they are not on the same platform.

Also, during the architecture task, requirements were allocated to the system's functions. The allocation process ensured that all requirements could be mapped to at least one function, meaning that the architecture addressed all of the C2 system requirements. The allocation process also ensured that all functions were allocated at least one requirement, meaning that all included C2 system functionality supported a system requirement. In cases where the allocation of requirements to the system functions was not complete, the architecture task fed the discrepancies back into the requirements definition to clarify the C2 system requirements. A specific example of the feedback to the requirements task includes the identification of three previously undocumented requirements: to allow the user to tailor the display, to receive and process the OPTASK LINK and to support the querying of commercial ships in support of MIO.

## **2. Methodology**

The DoDAF was used to describe the architecture for both the SUW and MIO missions. The framework defines three related views of the architecture: operational view (OV), systems view (SV), and technical standards view (TV). Due to the scope of this project, only the OV and SV were used. In addition to the OV-1 diagrams presented earlier in this report, three other DoDAF products were created: the operations activity model (OV-5), the system functionality description (SV-4), and the operational activities to systems function traceability matrix (SV-5). The OV-5 was created to show the capabilities, operational activities, relationships among activities, and inputs and outputs to the operational activities. The SV-4 shows the system functionalities and data flow among the system functions. The SV-5 shows the mapping of system functions to the operational activities.

In the development of the OV-5 and SV-4 products, the CORE Systems Engineering tool was used to document and integrate the products. CORE allows the use of either the Integration

Definition language 0 (IDEF0) or the Enhanced Functional Flow Block Diagram (EFFBD) methods for functional modeling. IDEF0 was specifically chosen as a language because it supports a good representation of concurrent systems that do not demonstrate sequential behavior. IDEF0 shows the tasks and information flows within a system. An IDEF0 diagram shows the inputs, controls, outputs, and mechanisms (ICOMS) for an activity or function. An input is an object that is changed as a result of the activity or function. A control is an object that guides or regulates the activity or function. An output is an object that is the result of the activity or function. A mechanism is a system, organization, people, etc. that support or perform the activity or function [National Institute of Standards and Technology, 2009]. The OV-5 and SV-4 diagrams below do not include any mechanisms. The architecture is intended to define the required functional behavior of the C2 system and not the design of the physical system itself.

During the development of the OV-5, the NTTL was referenced for operational activities [Office of the Chief of Naval Operations, 2007]. There were some specific cases where the activities defined were not directly taken from the NTTL. These cases were whenever there was an activity specific to the architecture that needed to be defined that was not clearly included within the NTTL.

The OV-5 development was also based upon the SUW and MIO mission threads defined in Section II.B “Mission Threads Analysis.” Key concepts of classification, identification, application of ROEs, input of weapon status, commercial ship queries, issuance of the engagement order and engagement assessment were translated directly into the OV-5. However, the OV-5 goes into greater detail than the mission threads in certain areas, specifically in the exchange of data via the track file, further decomposition of guidance such as ROE into preplanned responses, classification and identification criteria, weapons release criteria and expansion of external inputs such as intelligence data and Operation Tasks (OPTASK).

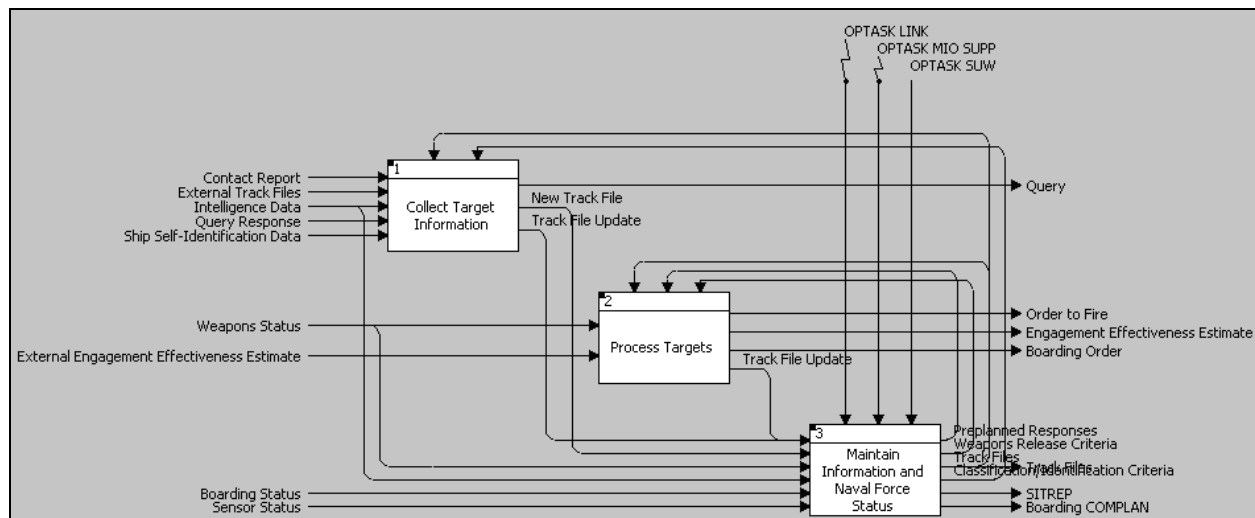
During the development of the SV-4, the Surface Navy Combat Systems Product Line Software Architecture: Architecture Description Document [Program Executive Office for Integrated Warfare Systems, 2008] was used as the source for the top-level functions, where the top-level functions map to the domains within the document. As with the OV-5, top-level functions were added as necessary when specific functionality needed to be called out that was not present within the Architecture Description Document at the domain level.

### 3. Architecture Products

The following diagrams represent the architecture for the C2 system. Figure 19 through Figure 22 and accompanying descriptions pertain to the OV-5 for the C2 system. Figure 23 is the external system diagram. Figure 24 through Figure 27 diagrams and descriptions pertain to the SV-4. Finally, the SV-5 is shown in Table 9.

#### *a. Operational Activities*

Perform C2 consists of three operational activities: Collect Target Information (NTA 2.2.1), Process Targets (NTA 3.1) and Maintain Information and Naval Force Status (NTA 5.1.3). The OV-5 A0 diagram for Perform C2 is shown in Figure 19.



**Figure 19: OV-5 A0 Diagram for Perform C2**

The OV-5 A0 Diagram contains three operational activities: Collect Target Information, Process Targets, and Maintain Information and Naval Force Status.

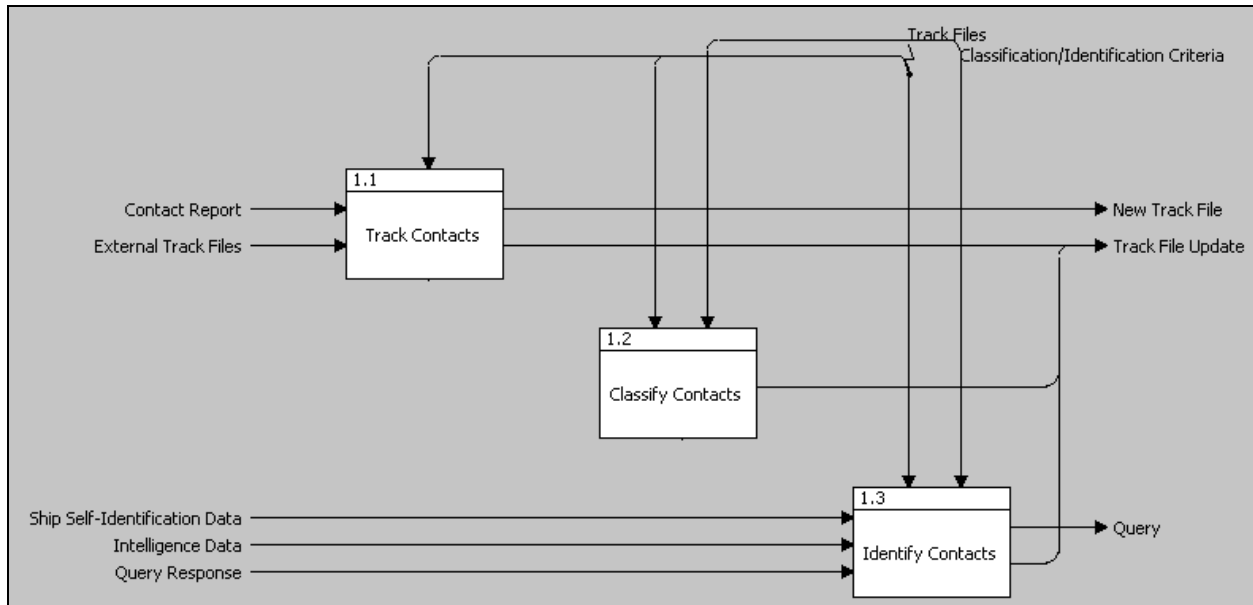
The first operational activity is “Collect Target Information,” which encompasses the tracking, classification, and identification of surface contacts. This activity uses, contact reports from external sensors, external track files, ship self-identification data from AIS, intelligence data as inputs, query responses from surface contacts. As controls, this activity uses the set of internally maintained track files and the classification and identification criteria. This activity outputs a query to a surface contact, new track file, or a track file update.

The second operational activity is “Process Targets,” which includes the selection of targets, the allocation of targets to weapons, and the issuance of the order to engage. This

activity uses weapons status and external engagement effectiveness estimates as inputs and outputs an order to fire, external engagement effectiveness estimates, boarding order, and track file updates indicating engagement status on the track. The controls for this activity are the weapons release criteria, the set of internally maintained track files, and the pre-planned responses.

The third operational activity is “Maintain Information and Naval Force Status,” which provides for the maintenance and display of the tactical picture, unit status, and force command and coordination status. This activity uses track file updates, new track files, intelligence data to maintain the tactical picture, and weapons, boarding, and sensor statuses to maintain unit status as inputs. The controls for this activity are the operation tasks (OPTASKs) LINK, MIO SUPP, and SUW. OPTASK LINK is the information required to establish the link network. OPTASK MIO SUPP describes the authority required to conduct each MIO task, rules of engagement, the format and frequency of situation reports (SITREPs), and any other specific required procedures during boarding. OPTASK SUW describes authorities, rules of engagement, reporting requirements, and other information required to conduct SUW operations. This activity outputs track files, the boarding communication plan (COMPLAN), and SITREPs to external commands. It uses the OPTASKs to produce a number of additional outputs that are controls for other activities, including the set of internal track files, weapons release criteria, pre-planned responses, and classification/identification criteria.

The “Collect Target Information” operational activity is decomposed into three sub-activities as shown in Figure 20. These sub-activities include the following: Track Contacts, Classify Contacts, and Identify Contacts.



**Figure 20: OV-5 A1 Diagram for Collect Target Information**

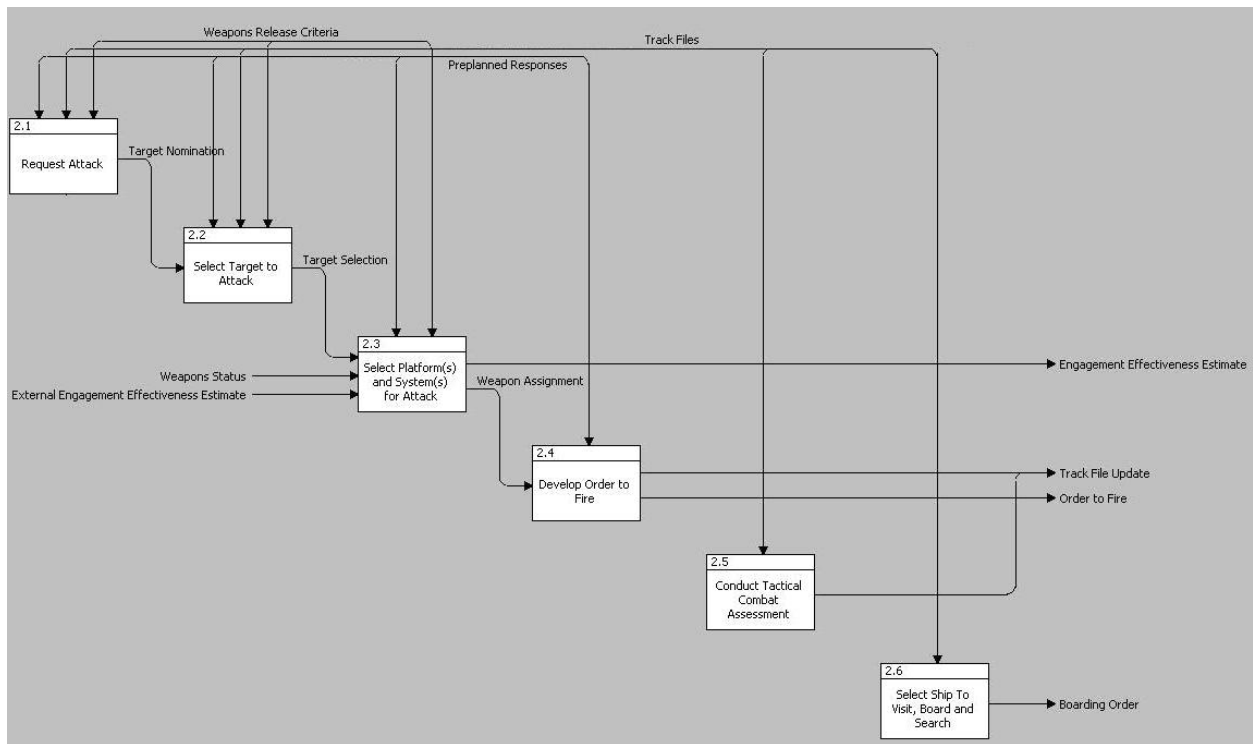
This figure is the decomposition of the “Collect Target Information” activity.

The first sub-activity is “Track Contacts,” which accepts inputs of contact reports from both own-ship and external systems as well as external track files. An internally maintained track file provides the control for this activity. The Track Contents activity utilizes these inputs to create an update to the internal track file, along with an output of a new external track file. The use of both own-ship and external contact reports in the generation of new track files and track file updates implements the EOR capability.

The second sub-activity is “Classify Contacts,” which requires the internal track file and classification and identification criteria as controls. These controls allow the activity to output a track file update with the classification parameters added.

The third sub-activity is “Identify Contacts,” which requires ship self-identification data from AIS, intelligence data, and query responses as inputs in conjunction with the internal track file and classification/identification criteria controls. This activity uses these outputs as a query to a surface contact and outputs a track file update with the identification parameters added.

The “Process Targets” operational activity is decomposed into six sub-activities as shown in Figure 21. These sub-activities include the following: Request Attack, Select Target to Attack, Select Platform(s) and System(s) for Attack, Develop Order to Fire, Conduct Tactical Combat Assessment, and Select Ship to Visit, Board, and Search.



**Figure 21: OV-5 A2 Diagram for Process Targets**

This figure is the decomposition of the “Process Targets” activity.

The first sub-activity is “Request Attack,” which utilizes the controls of weapons release criteria, pre-planned responses, and track files to develop a target nomination. This target nomination is output directly into the second sub-activity, “Select Target to Attack.” The “Select Target to Attack” sub-activity utilizes this input and the same controls as the first sub-activity to select a target, which is an output to the third sub-activity, “Select Platform(s) and System(s) for Attack.” These two activities employ a threat evaluation algorithm that is common across the force in support of Distributed Weapons Coordination.

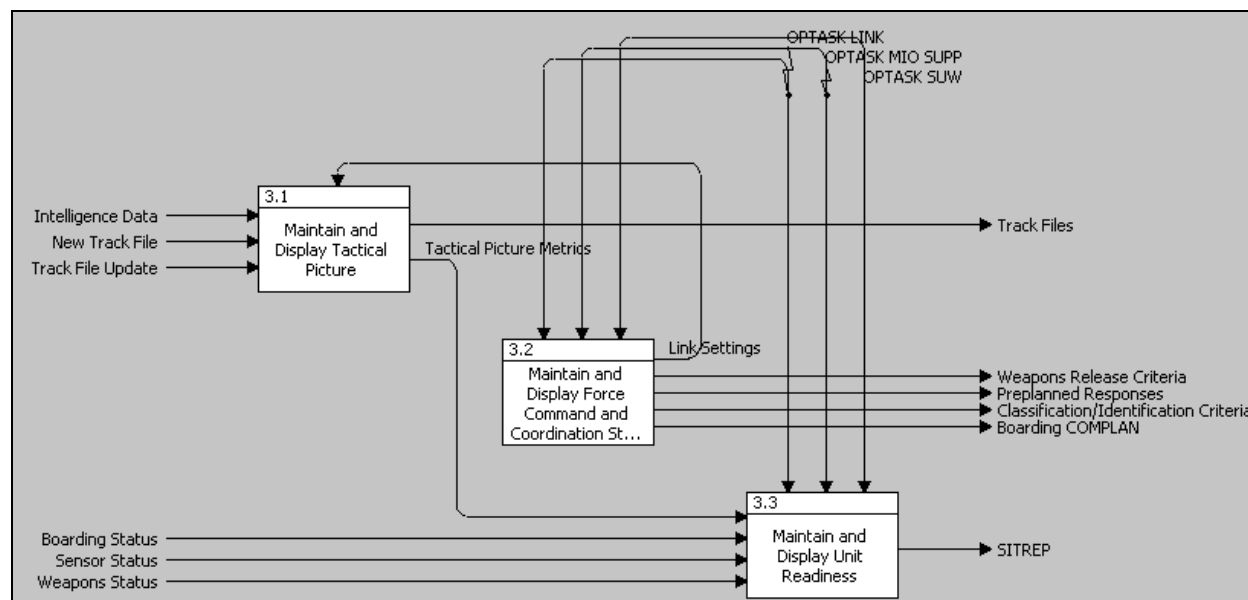
The “Select Platform(s) and System(s) for Attack” sub-activity utilizes target selection, weapons status, and external engagement effectiveness estimates as inputs. As controls, this activity uses the weapons release criteria and pre-planned responses. This activity outputs own-ship engagement effectiveness estimates and uses both own-ship and external engagement effectiveness estimates when executing an engagement scheduling algorithm that is common across the force to support DWC. This activity creates a weapon assignment.

The fourth sub-activity is “Develop Order to Fire,” which requires the weapon assignment as an input and the pre-planned responses as a control. This activity uses these inputs to generate an order to fire and a track file update.

The fifth sub-activity is “Conduct Tactical Combat Assessment,” which requires no input, but uses the track file as a control. Additional information is added to the track file, which leads to a track file update output.

The sixth sub-activity is “Select Ship to Visit, Board, and Search,” which requires no input and uses the track file as a control. This activity may output a boarding order, if a ship is selected to visit, board, and search. Obviously, this activity is distinct to a MIO activity and would not be activated in an engagement scenario. This sub-activity within the Process Targets activity reinforces the concept that the OV-5 is a common functional set that can be applied across both the SUW and MIO mission threads and all activities may not be applicable in all scenarios.

The “Maintain Information and Naval Force Status” operational activity is decomposed into three sub-activities as shown in Figure 22. These sub-activities include the following: Maintain and Display Tactical Picture, Maintain and Display Force Command and Coordination Status, and Maintain and Display Unit Readiness.



**Figure 22: OV-5 A3 Diagram for Maintain Information and Naval Force Status**

This figure is the decomposition of the “Maintain Information and Naval Forces Status” activity.

The first sub-activity is “Maintain and Display Tactical Picture,” which requires intelligence data, a new track file, and a track file update as inputs. This activity uses these inputs along with link settings from the second sub-activity, “Maintain Display Force Command and Coordination Status,” as a control to create track files and tactical picture metrics.

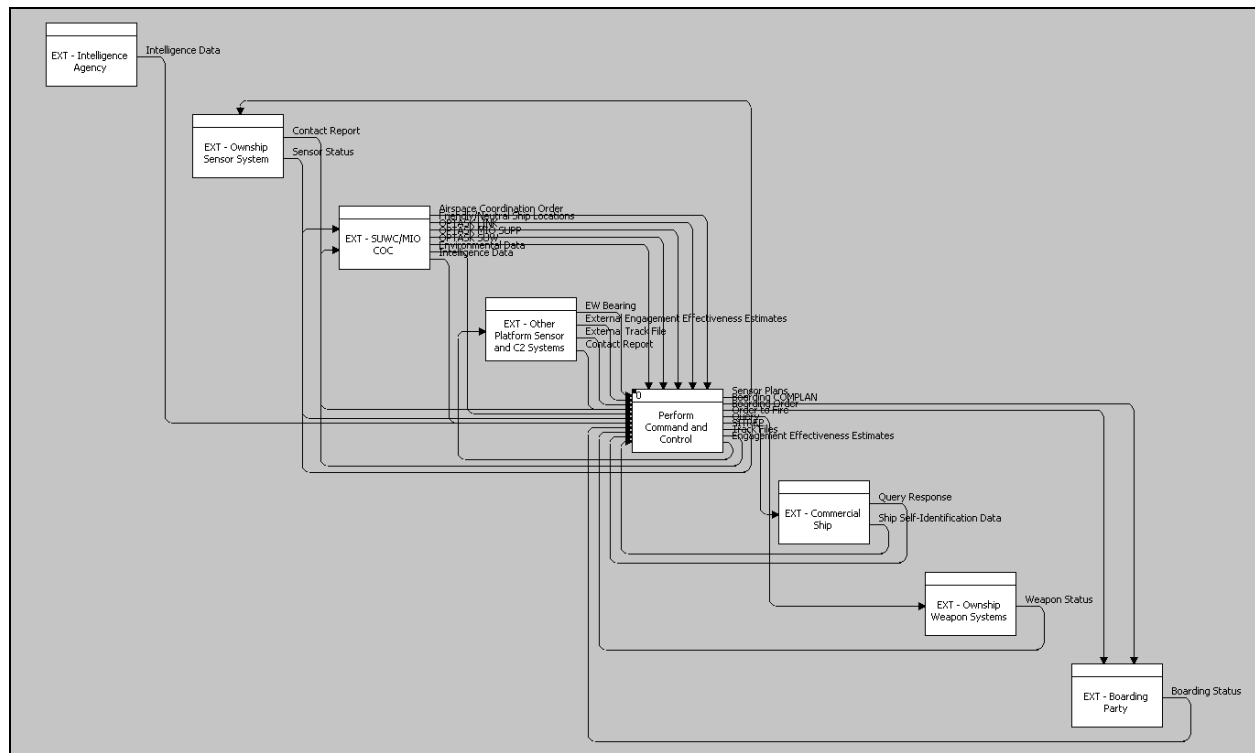
The “Maintain and Display Force Command and Coordination Status” sub-activity requires OPTASKs LINK, MIO SUPP, and SUW as controls to generate and output the link settings required in the “Maintain and Display Tactical Picture” sub-activity and to output classification and identification criteria, a boarding COMPLAN, weapons release criteria, and pre-planned responses.

The third sub-activity is “Maintain and Display Unit Readiness,” which utilizes the tactical picture metrics from the “Maintain and Display Tactical Picture” sub-activity, along with sensor, weapon, and boarding statuses as inputs. This activity uses the OPTASK LINK, OPTASK MIO SUPP, and OPTASK SUW as controls. This activity uses these inputs and controls to generate SITREPs.

#### ***b. Functional Descriptions***

The C2 system must interface with other own-ship and external systems or entities. An external system diagram shows the external systems and entities that the C2 system interfaces with and the data flows between them. The external systems are: intelligence agency, own-ship sensor systems, SUW Commander (SUWC) or MIO combat operations center (COC), other platform sensor and C2 systems, commercial ships, own-ship weapons systems, and boarding party. The A-1 external system diagram for Perform C2 is shown in Figure 23.

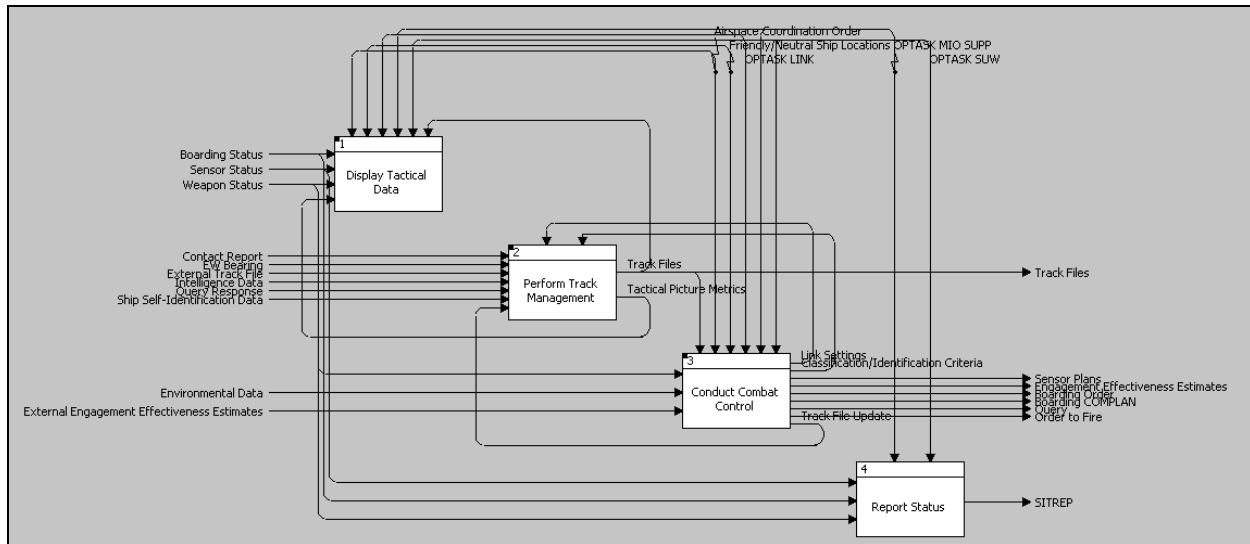




**Figure 23: A-1 External System Diagram for Perform C2**

This is the context diagram for the Perform C2 Function and depicts the external systems with which the C2 system interacts.

Perform C2 consists of four functions: Display Tactical Data, Perform Track Management, Conduct Combat Control, and Report Status. The SV-4 A0 diagram for Perform C2 is shown in Figure 24.



**Figure 24: SV-4 A0 Diagram for Perform C2**

The SV-4 A0 Diagram contains four operational activities: Display Tactical Data, Perform Track Management, Conduct Combat Control, and Report Status.

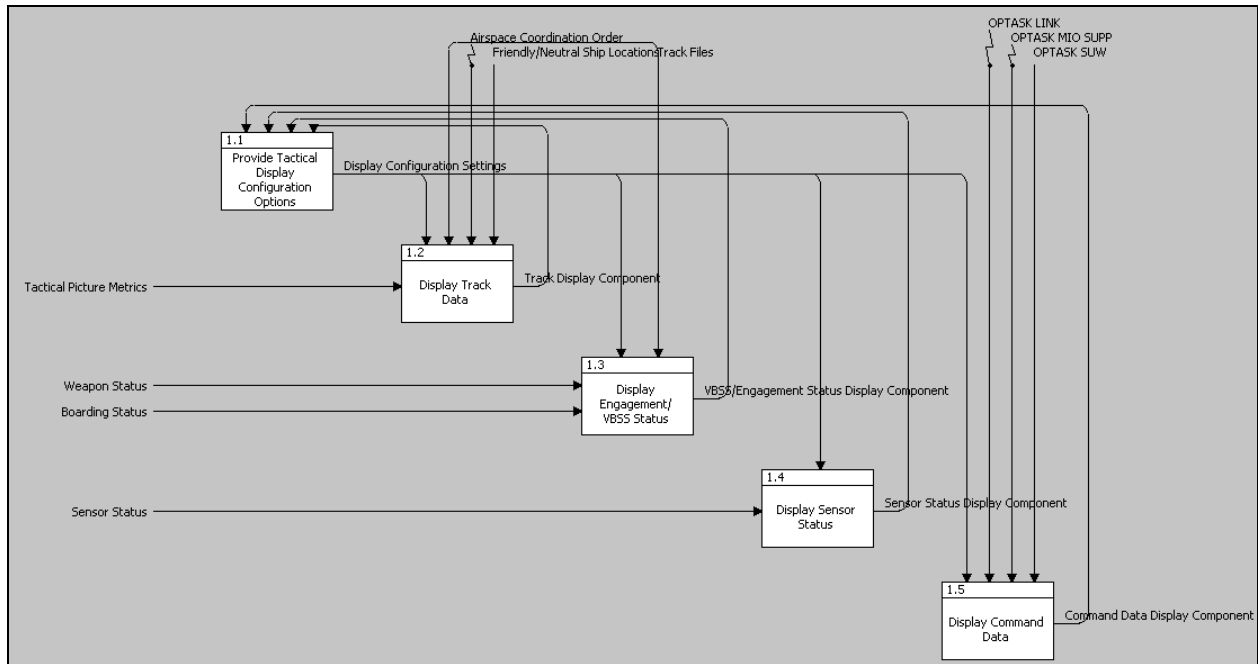
The first function is “Display Tactical Data,” which includes displaying tactical data and various statuses. This function uses boarding, sensor, and weapon statuses and tactical picture metrics as inputs. As controls, this function uses the following: the set of internally maintained track files from the second function “Perform Track Management,” OPTASKs LINK, MIO SUPP, and SUW, airspace coordination orders, and friendly and neutral ship locations. This function does not have any outputs. The “Display Tactical Data” function produces the display as output to the system operator. The decision was made to leave the display output off the diagram as it was inconsistent with outputs such as Track Files that represent data exchanged between functions.

The “Perform Track Management” sub-function consists of the formation, classification, identification, correlation and decorrelation, and bearing and fix association of tracks. This function uses several inputs: ship self-identification data from AIS, contact reports from external sensors, electronic warfare (EW) bearings, external track files, intelligence data, query responses, and track file updates from the third function “Conduct Combat Control.” The controls for this function are the link settings and classification and identification criteria from the “Conduct Combat Control function.” This function outputs track files, which the “Display Tactical Data” function also uses as a control, and tactical picture metrics, which is an input to the “Display Tactical Data” function.

The third function is “Conduct Combat Control,” which includes assessing and prioritizing threats, issuing engagement or boarding orders, and assessing the engagement. This function utilizes weapon status, environmental data, and external engagement effectiveness estimates as inputs. The controls for this function are the same as the ones used by the “Display Tactical Data” function. Track files are represented as a control and not as an input because they guide how the function prioritizes threats, issues orders and assesses engagement. However, the track files are not directly modified by the function during execution. Track file updates are produced and incorporated into the track files within the Track Management function. The “Conduct Combat Control” function has several outputs: link settings and classification and identification data, which are used as controls by the “Perform Track Management” function, sensor plans, order to fire, queries, boarding orders, boarding COMPLAN, and track file updates, which are used as an input by the “Perform Track Management” function. The “Conduct Combat Control” function also exports engagement effectiveness estimates in support of the Distributed Weapons Control concept.

The fourth function is “Report Status,” which includes the sending of SITREPs to higher-level commands. This function used boarding, sensor, and weapon statuses as inputs. The controls for this function are OPTASKs MIO SUPP and OPTASK SUW. This function utilizes these inputs and controls to generate SITREPs.

The “Display Tactical Data” function is decomposed into five sub-functions as shown in Figure 25. These sub-functions include the following: Provide Tactical Display Configuration Options, Display Track Data, Display Engagement or VBSS Status, Display Sensor Status, and Display Command Data.



**Figure 25: SV-4 A1 Diagram for Display Tactical Data**

This figure is the decomposition of the Display Tactical Data function.

The first sub-function is “Provide Tactical Display Configuration Options,” which does not have any inputs, but uses the display output from the four display functions as a control. The display output serves as a control to the “Provide Tactical Display Configuration Options” function because the function does not directly modify the display. Rather, the function provides display setting to the various display functions. This function outputs display configuration settings, which are used as a control for the four display functions.

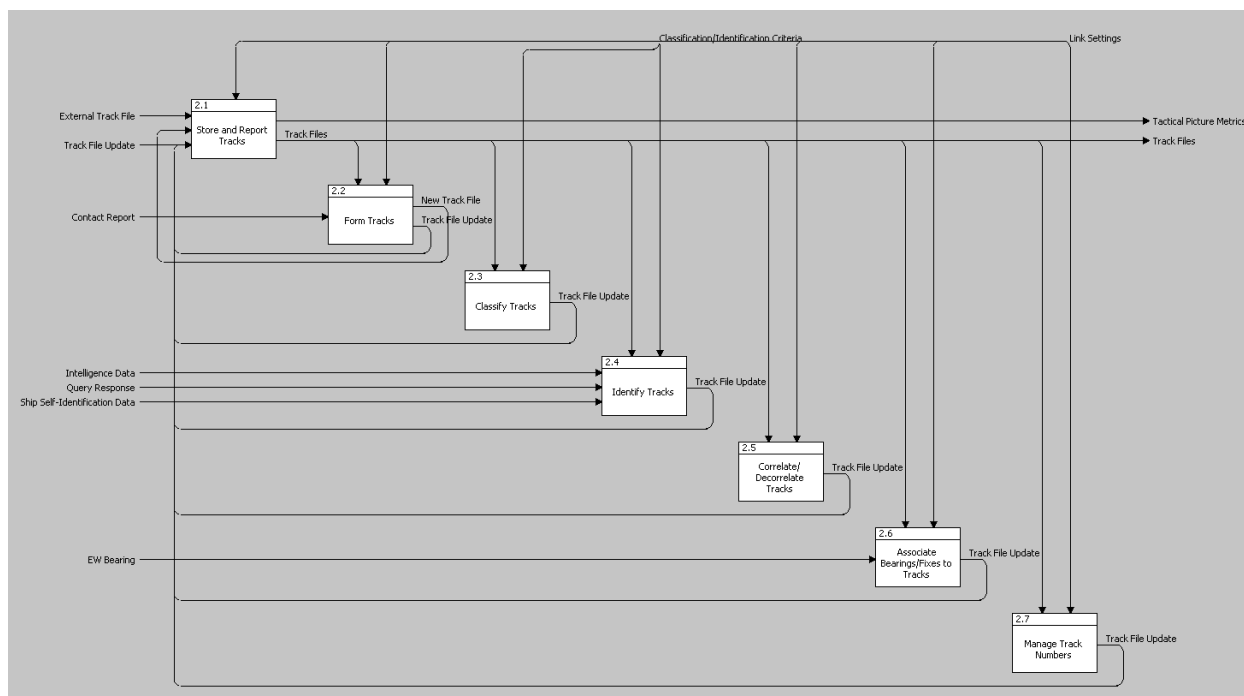
The second sub-function is “Display Track Data,” which uses tactical picture metrics as an input. The controls for this function are the display configuration settings from the “Provide Tactical Display Configuration Options” function, airspace coordination order, friendly and neutral ship locations, and track files. This function provides the display component for track data.

The third sub-function is “Display Engagement/VBSS Status,” which uses weapon and boarding statuses as inputs. The controls for this function are the display configuration settings from the “Provide Tactical Display Configuration Options” function and track files. This function provides the display component for VBSS and engagement status data.

The fourth sub-function is “Display Sensor Status,” which includes sensor status as an input. The control for this function is the display configuration settings from the “Provide Tactical Display Configuration Options” function. This function provides the display component for sensor status.

The fifth sub-function is “Display Command Data,” which does not have any inputs, but uses OPTASK LINK, OPTASK MIO SUPP, and OPTASK SUW and the display configuration settings from the “Provide Tactical Display Configuration Options” function as controls. This function provides the display component for command data, such as the OPTASKs.

The “Perform Track Management” function is decomposed into seven sub-functions as shown in Figure 26. These sub-functions include the following: Store and Report Tracks, Form Tracks, Classify Tracks, Identify Tracks, Correlate and Decorrelate Tracks, Associate Bearings and Fixes to Tracks, and Manage Track Numbers.



**Figure 26: SV-4 A2 Diagram for Perform Track Management**

This figure is the decomposition of the Perform Track Management function.

The first sub-function is “Store and Report Tracks,” which uses external track files, track file updates from the six other sub-functions, and new track files from the second sub-function,

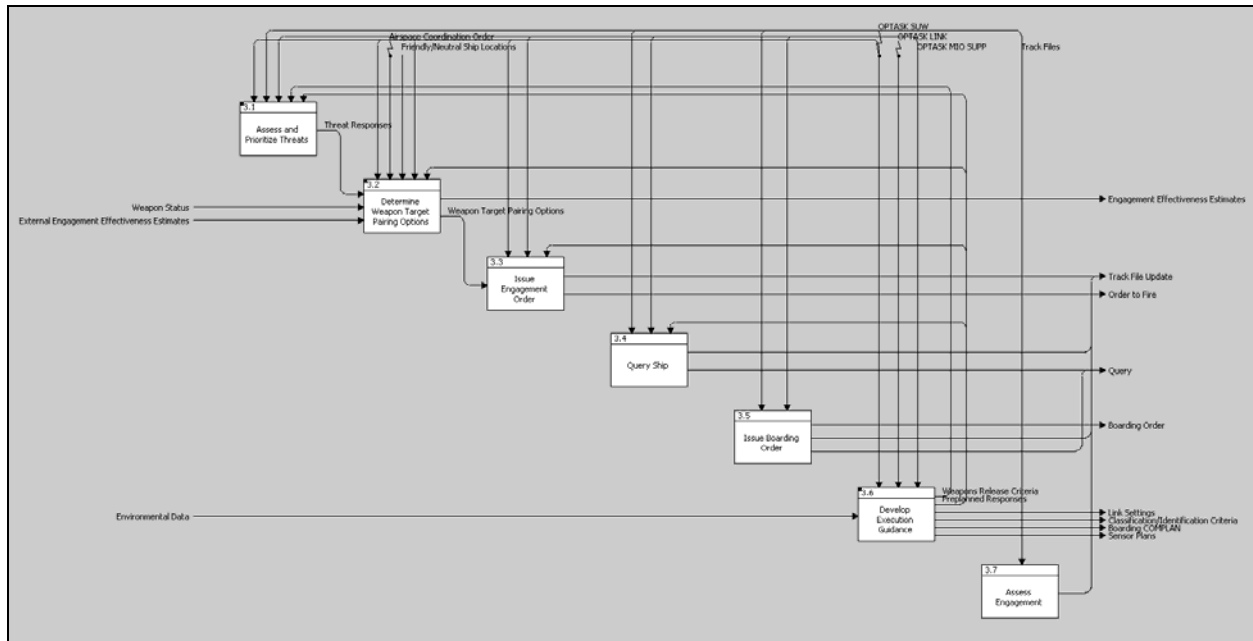
“Form Tracks,” as inputs. The control for this function is the link settings. This function outputs tactical picture metrics and track files that are used as controls by the six other sub-functions.

The “Form Tracks” sub-function uses contact reports from own-ship and external sources as an input. The controls for this sub-function are link settings and track files from the “Store and Report Tracks” sub-function. New track files and track file updates are outputs that are then used as inputs to the “Store and Report Tracks” sub-function. The use of both own-ship and external contact reports to form new track files and track file updates represents the EOR capability.

The third and fourth sub-functions are “Classify Tracks” and “Identify Tracks,” respectively. The “Classify Tracks” sub-function does not have an input while the “Identify Tracks” sub-function uses intelligence data, query responses, and ship self-identification data from AIS as inputs. Both use track files and classification and identification criteria as controls and output track file updates.

The fifth, sixth, and seventh sub-functions are “Correlate/Decorrelate Tracks,” “Associate Bearings/Fixes to Tracks,” and “Manage Track Numbers,” respectively. The “Correlate/Decorrelate Tracks” and “Manage Track Numbers” sub-functions do not have any inputs while the “Associate Bearings/Fixes to Tracks” sub-function uses EW bearings as an input. Each sub-function use link settings and track files as controls and outputs track file updates.

The “Conduct Combat Control” function is decomposed into seven sub-functions as shown in Figure 27. These sub-functions include the following: Assess and Prioritize Threats, Determine Weapon Target pairing Options, Issue Engagement Order, Query Ship, Issue Boarding Order, Develop Execution Guidance, and Assess Engagement.



**Figure 27: SV-4 A3 Diagram for Conduct Combat Control**

This figure is the decomposition of the Conduct Combat Control function.

The first sub-function is “Assess and Prioritize Threats,” which does not have an input, but uses OPTASKs MIO SUPP and SUW, track files, and outputs from the “Develop Execution Guidance” sub-function, pre-planned responses, and weapons release criteria as controls. To support the DWC concept, the “Assess and Prioritize Threats” sub-function uses a threat evaluation algorithm that is common across the force. This sub-function outputs threat responses directly into the second sub-function “Determine Weapon Target Pairing Options.”

The “Determine Weapon Target Pairing Options” sub-function uses the threat responses from the “Assess and Prioritize Threats” sub-function and weapon status as inputs. The controls, for this sub-function are airspace coordination order, friendly and neutral ship locations, pre-planned responses from the sixth sub-function “Develop Execution Guidance,” and OPTASKs MIO SUPP and SUW. The “Determine Weapon Target Pairing Options” sub-function supports the DWC concept by exporting own-ship engagement effectiveness estimates and by using both own-ship and external engagement effectiveness estimates as inputs to develop the weapon-target pairing options. This sub-function outputs weapon target pairing options directly into the third sub-function “Issue Engagement Order.”

The “Issue Engagement Order” sub-function’s only input is the aforementioned weapon target pairing options. The controls for this sub-function are OPTASKs MIO SUPP and SUW

and pre-planned responses from the “Develop Execution Guidance” sub-function. In support of DWC, the “Issue Engagement Order” sub-function employs a weapon scheduling algorithm that is common across the force. This sub-function outputs a track file update and an order to fire.

The fourth sub-function is “Query Ship,” which does not have an input, but uses OPTASK MIO SUPP, track files, and pre-planned responses from the “Develop Execution Guidance” sub-function as controls. This sub-function outputs a track file update and a query.

The fifth sub-function is “Issue Boarding Order,” which does not have an input, but uses OPTASK MIO SUPP and track files as controls. This sub-function outputs a track file update, a query, and a boarding order.

The sixth sub-function is “Develop Execution Guidance,” which uses environmental data as an input. The controls for this sub-function are OPTASKs LINK, MIO SUPP, and SUW. Outputs for this sub-function include: sensor plans, link settings, classification and identification criteria, boarding COMPLAN, pre-planned responses, and weapons release criteria.

The seventh sub-function is “Assess Engagement,” which does not have an input and uses track files as a control. This sub-function outputs a track file update.

After creating the OV-5 and SV-4 diagrams, the SV-5 was created to show the traceability between the operational activities and system functions as shown in Table 9. In an SV-5, only the leaf-level functions are mapped to their corresponding leaf-level operational activities. The top-level functions and operational activities are included in the diagram to help the reader trace the system function to operational activity mapping to the architecture diagrams. An ‘X’ placed in the matrix indicates that the system function implements that operational activity. All system functions map to at least one operational activity and vice versa. This ensures that all activities are supported by the system functions and that no system functions exists that do not support some operational activity. The verification of the enterprise architecture is discussed in Section IV.A “Modeling and Simulation”.



**Table 9: SV-5**

The table indicates which system functions are used to satisfy the operational activities.

Functions	Operational Activities												
	0 Perform Command and Control	1 Collect Target Information	1.1 Track Contacts	1.2 Classify Contacts	1.3 Identify Contacts	2 Process Targets	2.1 Request Attack	2.2 Select Target to Attack	2.3 Select Platform(s) and System(s) for Attack	2.4 Develop Order to Fire	2.5 Conduct Tactical Combat Assessment	2.6 Select Ship To Visit, Board and Search	3 Maintain Information and Naval Force Status
0 Perform Command and Control													
1 Display Tactical Data													
1.1 Provide Tactical Display Configuration Options													X
1.2 Display Track Data													X
1.3 Display Engagement/VBSS Status													X
1.4 Display Sensor Status													X
1.5 Display Command Data													X
2 Perform Track Management													
2.1 Store and Report Tracks			X										X
2.2 Form Tracks			X										
2.3 Classify Tracks				X									
2.4 Identify Tracks					X								
2.5 Correlate/Decorrelate Tracks			X										
2.6 Associate Bearings/Fixes to Tracks			X										
2.7 Manage Track Numbers			X										
3 Conduct Combat Control													
3.1 Assess and Prioritize Threats													
3.1.1 Identify Threats						X							
3.1.2 Prioritize Threats						X	X						
3.1.3 Identify Actions Required for Each Threat							X						
3.2 Determine Weapon Target Pairing Options													
3.2.1 Estimate Engagement Effectiveness								X					
3.2.2 Identify Engagement Conflicts								X					
3.2.3 Compile Weapon Target Pairing Options								X					
3.3 Issue Engagement Order									X				
3.4 Query Ship				X									
3.5 Issue Boarding Order											X		
3.6 Develop Execution Guidance													
3.6.1 Develop Engagement Guidance													X
3.6.2 Develop Sensor Plans													X
3.6.3 Develop Track Management Policy													X
3.7 Assess Engagement										X			
4 Report Status												X	X

#### 4. Conclusions

The required behavior of the C2 system, which was based on the system's requirements, was defined by the enterprise architecture. This enterprise architecture for the C2 system can effectively support both the SUW and MIO missions without the need for separate C2 system architectures. The operational activities that the systems support are defined by the OV-5 diagrams. Then, the external system diagrams are used to show the external systems and entities that the system interfaces with to support the mission. Next, the C2 system's functions are

defined by the SV-4 diagrams. Finally, the system's functions are mapped to the operational activities via the SV-5. During the M&S task, which is described later in this report, COREsim and CPN validate the architecture to ensure that it is consistent and executable.

## IV. MODELING AND ANALYSIS

The Modeling and Analysis phase provides modeling and simulation results to verify the architecture, and cost analysis to identify and quantify potential cost savings as a result of adopting a common C2 architecture for Navy surface combatants. Similar to the previous phase, the requirements, architecture, mission threads, and threats were re-evaluated as appropriate and the stakeholders were contacted in order to ensure the project remained on task with the stakeholders' needs (as verifying the architecture served as an integral part of the requirements and architecture development process). The Modeling and Analysis phase resulted in architecture verification and summarized analysis of the life-cycle cost savings from the consolidation of training modules.

### A. MODELING AND SIMULATION

Two different, but complementary, M&S techniques were used to model the C2 system architecture: discrete-event simulation using COREsim, and state space analysis using Colored Petri Nets (CPN). The objectives for the verification effort were to determine architecture completeness, to assess internal consistency within the architecture, and to verify that the architecture was executable. If not complete, consistent, and executable, then the M&S activities identify the specific deficiencies and adjustments needed to correct the architecture. COREsim supports architecture verification by demonstrating successful execution of an Enhanced Functional Flow Block Diagram (EFFBD) representation of the architecture through a finite number of simulation runs. CPN uses a state space analysis to identify logical issues that might not be uncovered in a fixed number of simulation runs.

#### 1. Architecture Verification using COREsim

##### *a. COREsim Background*

CORE is a model-based systems engineering (MBSE) tool with an integrated discrete event simulator called COREsim, which is used to create and execute a dynamic view of the architecture in order to verify logic, sequencing, and information flows. COREsim uses the Enhanced Functional Flow Block Diagram (EFFBD) view of the architecture associated with

both the OV-5 and SV-4. The EFFBD, as a dynamic process-oriented view of the architecture, provides information about operational activities or system functions that are not captured by the other views, such as sequencing of events. The EFFBD also uses logic control constructs to specify the behavior of the system in response to stimuli (called triggers in CORE). Use of the simulator to step through the dynamic process model can reveal errors in the flow of information between activities or functions that are not apparent by looking at the IDEF0 diagrams.

The default EFFBD views, produced automatically within CORE for both the operational activities and the system functions, show all activities and functions in numeric sequential order along a single branch. To provide a more realistic view of the dynamic system, the model can be modified to include a variety of logic structures, such as parallel branches, “and/or” and “if/then/else” constructs, iterates, loops, and exits. CORE documentation [Vitech Corp, 2000] indicates that there are two ways to represent the concept of concurrency. The first is through the “iterate” construct, which allows for the processing of multiple tracks in sequence (not truly concurrent). The second is through the “replicate” construct, which allows for the processing of multiple tracks simultaneously from a single control function. However, since the “replicate” construct is not currently enabled in CORE, there is no explicit way to represent the parallel processing of multiple tracks or targets. Parallel branches can be used to represent the concurrent processing of activities or functions, but applies to only one target or track at a time.

### ***b. Verification Techniques***

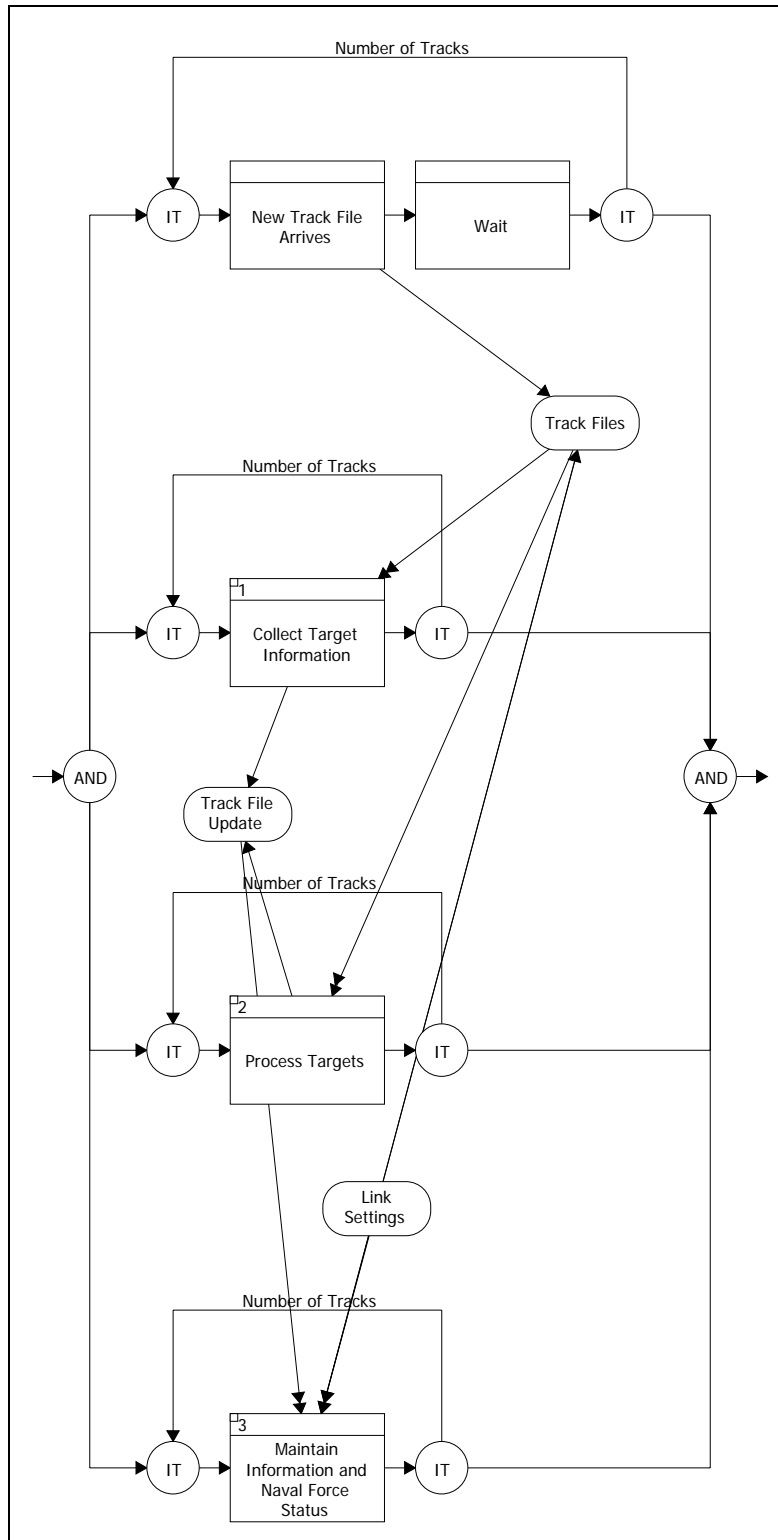
COREsim was used to develop and execute the EFFBD views of both the operational activities and the system functions. Modifications were made to accommodate the differences between the IDEF0 specification and the COREsim EFFBD modeling conventions in order to create an executable model. The default EFFBDs were not executable due to violations of COREsim rules. COREsim reads IDEF0 controls as triggers in the EFFBDs, which is not desirable for items such as doctrinal or other guidance documents. A trigger in the EFFBD is used to initiate the execution of an activity or function. A control in IDEF0 is used to represent information that guides or regulates how an activity is supposed to execute.

COREsim also requires all triggers to come from activities or functions that are explicitly represented in the model. As an example, information from external sensor systems are represented as controls on the C2 system in the IDEF0 diagrams, but are treated as triggers in the

EFFBD. These triggers were converted to inputs in order to allow the simulation to execute. Then the activity “New Track File Arrives” was added to the C2 operational activity EFFBD (Figure 28) to provide the initial triggering function as a proxy for the external sensor systems. The activity “Wait” was also added to the C2 operational activity EFFBD (Figure 28Figure 28: ) to control the time lapse between track arrivals. Similar changes were made to the C2 system function EFFBD (Figure 31).

The conversion of external system IDEF0 controls to EFFBD inputs and the addition of activities and functions to make the EFFBD executable substantively changed the IDEF0 representation of the architecture. Thus, it was necessary to maintain two versions of the CORE model; the original with properly described IDEF0 diagrams and a simulation version with COREsim executable EFFBDs.

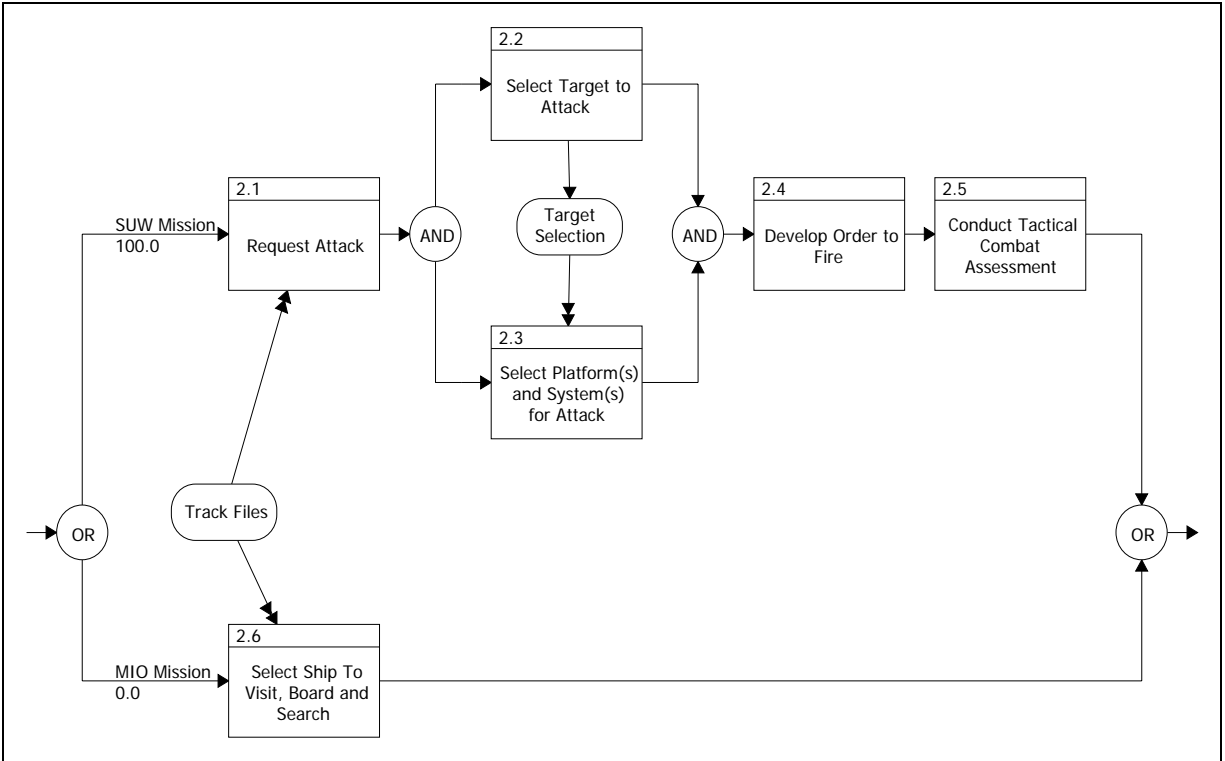
In addition to the adjustments required to allow the EFFBDs to execute in COREsim, adjustments were made to the sequencing of activities and functions to more closely reflect reality. Parallel processing was used to reflect concurrency of the operational activities and system functions, where applicable. Triggers were used to control sequencing of events between parallel branches. The “iterate” function was employed to allow for sequential processing of multiple tracks in a single run of the simulator. Figure 28 shows the top-level C2 operational activities, arranged in parallel, with iterations (labeled as “IT” in the diagram) to allow representation of multiple successive tracks.



**Figure 28: EFFBD of Top-Level C2 Operational Activities**

This EFFBD displays the top-level operational activities executed in parallel, with iteration to support successive multiple targets within a single run of the simulation.

The input and output information flows have been suppressed in the figures to make the diagrams easier to read, but all are included and used in the simulation. Triggers are shown in ovals with double-headed arrows. All of the sub-model EFFBD for operational activities were created and are available in Appendix D. The second-tier of the operational activity model for the “Process Targets” activity is shown in Figure 29. In this particular implementation of the model, a 100% probability is assigned to the upper branch in order to test only the ability to process the SUW related activities. The MIO mission is represented by the activity on the lower branch. To toggle between the mission threads, the branch probabilities can be assigned as 100% and 0% or vice versa. It is also possible to assign other combinations of probabilities to each branch (such as 50% and 50%), and to have both types of missions occur within a single run of the simulator. Variations were tested to ensure that the model executes as expected. There are numerous alternative ways that this could have been modeled, including multi-exit functions that select the appropriate branch using control logic and exceptions logic that bypass both of those options. For modelers with coding skills, the CORE scripting language could also be used to add more fidelity to the model.

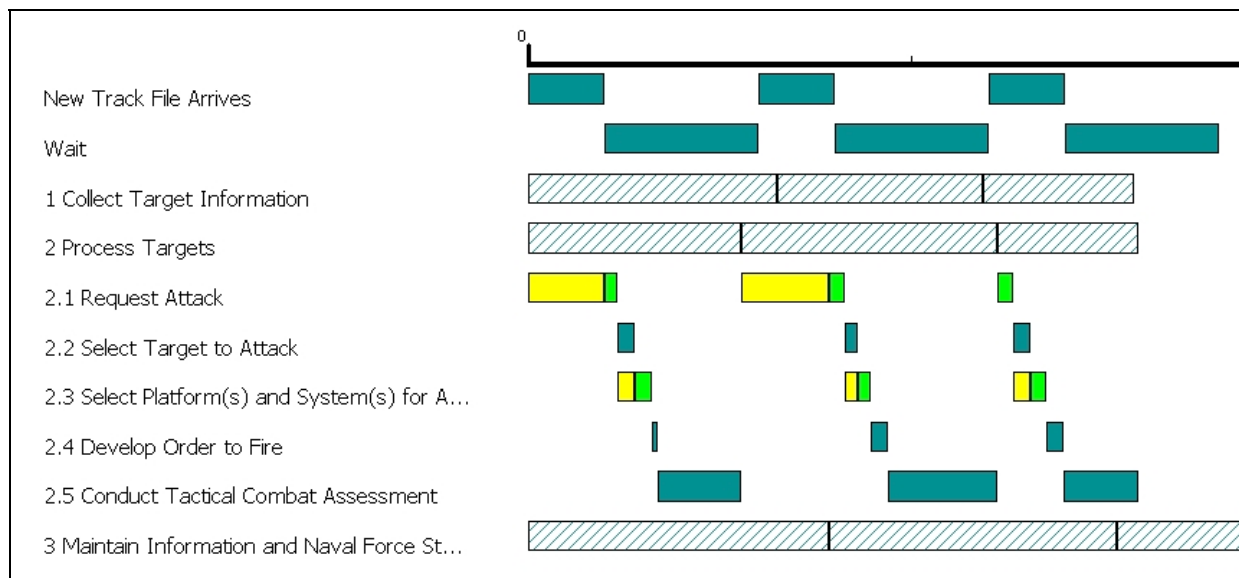


**Figure 29: Target Processing C2 Operational Activities**

This EFFBD is the decomposition of the “Process Targets” Operational Activity. The top branch includes activities associated with the SUW mission. The bottom branch shows the activity associated with MIO.

Figure 30 is a graphical representation of the COREsim output of a single simulation run. In this simulation run, the C2 operational activities process three track files, which represent targets, arriving in succession. The existence of a graphical representation of the simulation run indicates that the simulation executes with no technical errors.





**Figure 30: COREsim Results from C2 Operational Activities**

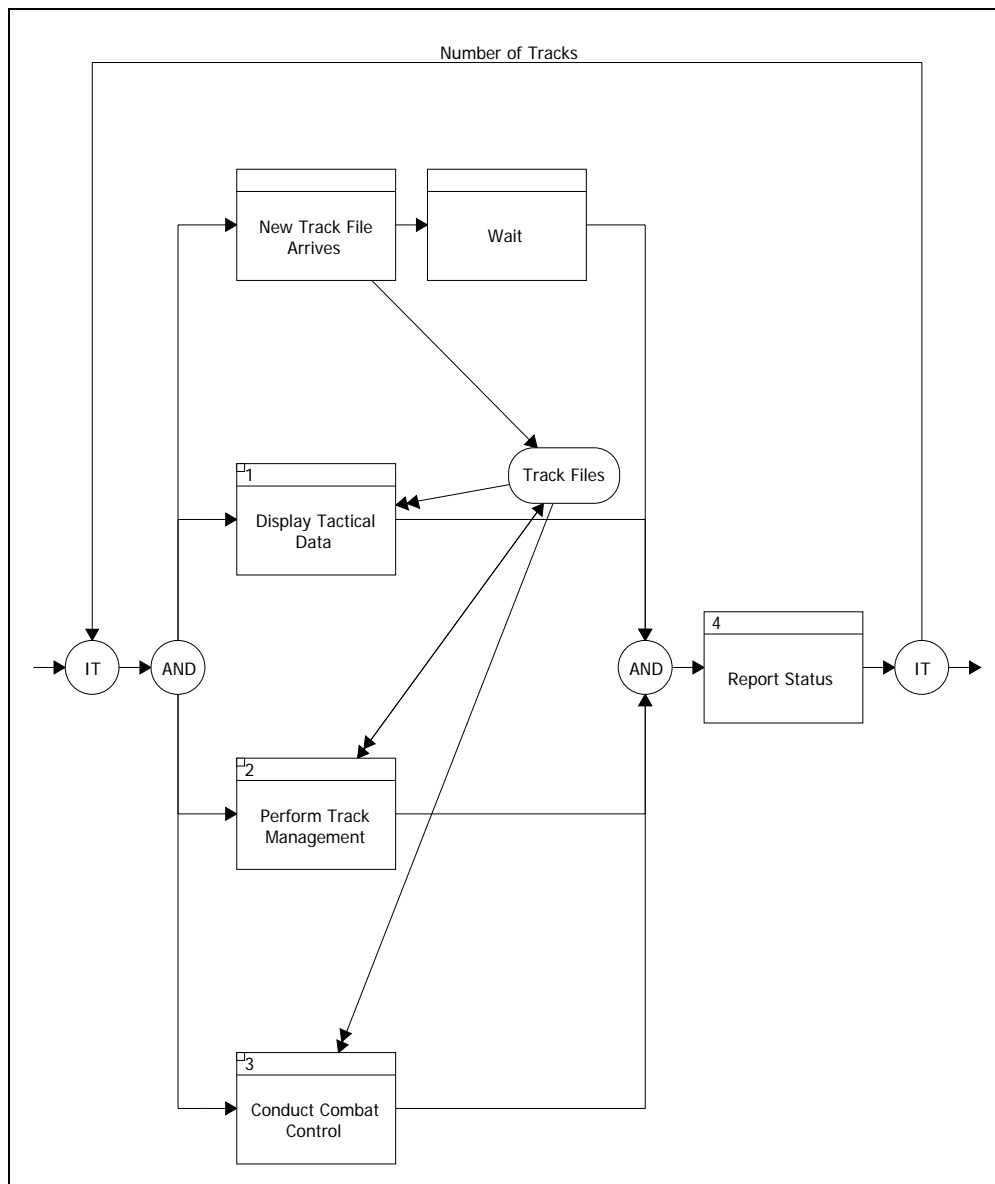
This figure shows the COREsim model results for three targets arriving in succession. Each track is processed and there are no errors in the model.

The operational activity names are listed in the column on the left. The corresponding rectangles on the right side of the diagram indicate blocks of time allotted to each activity. Dark green blocks correspond with activities that have no trigger, while the light green indicates that the activity was triggered by outputs from another activity. The yellow indicates a period of time that the activity is actively waiting to be triggered. The boxes with hatching marks represent the rolled up higher-level activities. The decomposition is not shown for those activities that are both continuous and concurrent in order to focus attention on the sequential activities as they apply to each track.

Timing can be independently specified for each activity or function as a constant value, a probability distribution (a variety of distributions are available) or in accordance with a CORE script. For this project, the COREsim model was used to verify the structure of the architecture, not to validate the time-based performance measures as developed in the value system design. As a consequence, the time values used were not relevant to the objectives of the assessment and set solely to improve the readability of the diagram.

The corresponding EFFBDs and results from COREsim are shown for the SV-4 diagrams in Figure 31, Figure 32 and Figure 33. Figure 31 shows the top-level C2 system functions

arranged in parallel with a single “iterate” construct to allow for multiple successive targets. All of the sub-model EFFBD for system functions were created and are available in Appendix D.

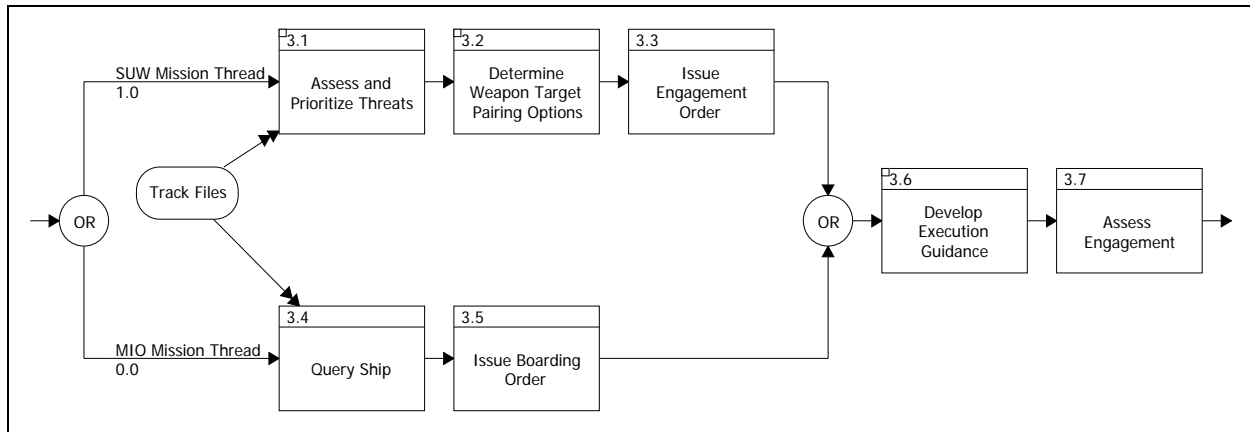


**Figure 31: EFFBD of Top-Level C2 System Functions**

This figure shows the top-level system functions as an EFFBD, where each function is executed in parallel to support multiple targets.

Figure 32 is focused on the second-tier of “Conduct Combat Control,” where the SUW mission is represented by the upper branch and assigned a probability of 100%, while the

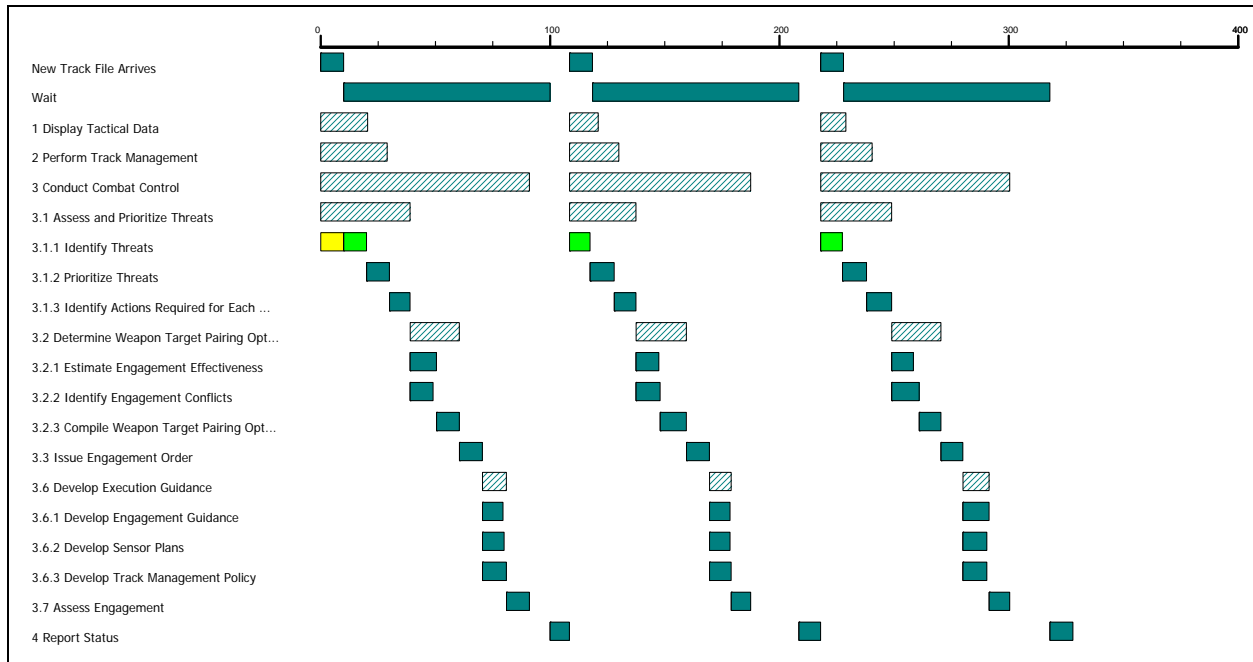
MIO mission is represented by the lower branch and assigned a probability of 0% (for this specific simulation run).



**Figure 32: Conduct Combat Control C2 Functions**

This figure shows the child functions of the Conduct Combat Control function. The separate branches show the functions associated with the SUW and MIO missions.

Results of a simulation run using just the SUW mission thread are shown in Figure 33. The graphic shows the relative sequencing and concurrency of the “Conduct Combat Control” C2 functions. The model runs without error. The continuous functions, “Display Tactical Data” and “Perform Track Management,” have been collapsed to focus on the details of the sequential processing of each target in “Conduct Combat Control.” As with the operational activities model, the timing for each function could be adjusted and defined as either a constant, a probability distribution, or in accordance with a script. In this model, the only adjustment made to the default timing was to extend the “Wait” time so that it is easier to make the visual linkage between the “Conduct Combat Control” functions and the associated track file in the top line. As with the operational activities, there is no basis for making changes to the default constant value, as there is no objective to validate the time-based system performance requirements at this stage.



**Figure 33: COREsim Results from C2 System Functions**

The figure shows the result of three targets arriving in succession. No errors were found during execution.

### *c. Results*

Within the limited scope of the COREsim assessment, no logical flaws in the architecture were identified. The EFFBDs could be enhanced, adding control functions to more explicitly portray decision points, but these were not absolutely necessary to verify the architecture. There was value in the EFFBDs, which provided additional information about the sequencing of the activities and functions. The process of developing the EFFBD views provided greater understanding of the architecture.

The full functionality of COREsim was not explored; but the timing capabilities could possibly be used in the context of the larger weapon system, supporting tradeoff decisions between C2 and engagement system time allocations and using the threat assessment results to bound the problem space. The results of timing studies could assist in identification of the specific physical implementation of the system. Also not used was the resource constraint capability in COREsim. This is also useful when evaluating engagement systems, as there are always constraints on resources such as ammunition. The constraint requirements developed for

this project were enterprise-level constraints that were not directly applicable to the C2 system modeling of a specific tactical engagement.

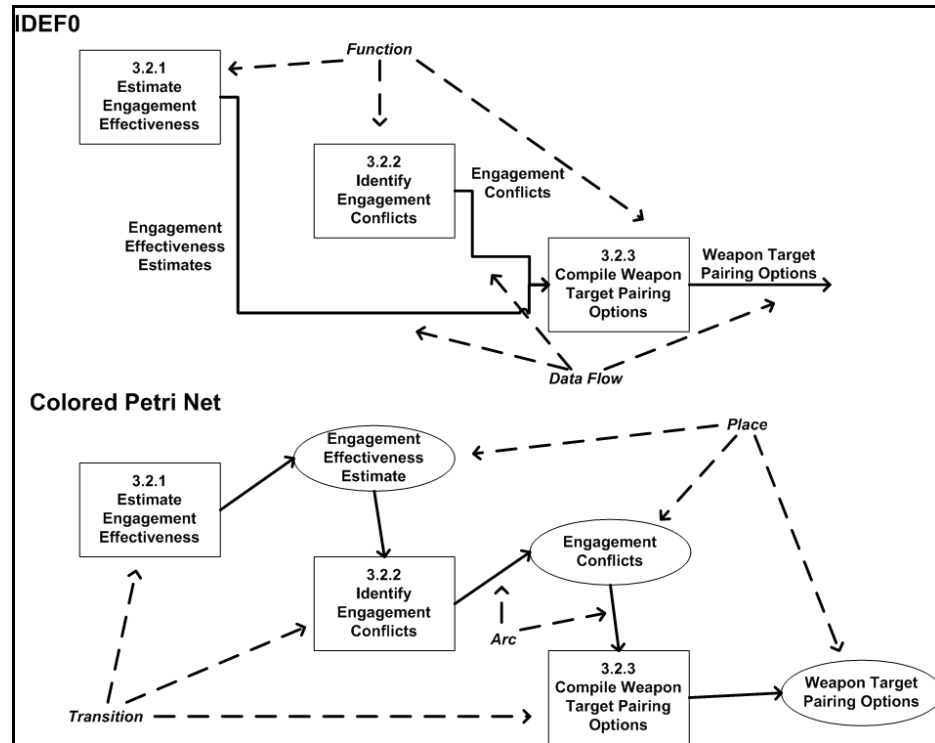
CORESim requires the use of parallel branching, iterations, loops and triggers to approximate the concurrency inherent in the IDEF0 diagrams. Due to the complexity of these changes, the CORESim assessment was focused on a small segment of the architecture. To fill in these gaps, and more thoroughly assess the logical consistency of the architecture, CPN modeling was used.

## **2. Architecture Verification Using Colored Petri Nets**

### ***a. Colored Petri Net Background***

The CPN language was developed specifically for the purpose of modeling and verification of concurrent, distributed systems. A CPN model represents the states of a system and the events that may cause the system to change state [Jensen, 2009]. Due to the way CPNs are specified, models can be simulated or assessed logically through a state space analysis.

The CPN modeling language consists of three elements: places, transitions, and arcs. Places represent data that is available within the system and is specified by a color, better known as a data type. Transitions are processes that take data from places, convert that data and send output data to other places. Transitions are specified by a guard condition that limits data that can be accepted by the transition and by the transition's code segment, which defines how input data is processed. Arcs define the paths, from places to transitions and transitions to places, which the data may follow [Jensen, 2009]. To provide a parallel to the SV-4 System Functionality Description in DoDAF, a transition is equivalent to a system function while an arc-place-arc combination is equivalent to a data flow (an example is shown in Figure 34).



**Figure 34: Example Mapping of IDEF0 to CPN**

The figure shows the mapping of an IDEF0 diagram to a CPN. A function in IDEF0 maps to a transition in CPN, while a data flow in IDEF0 maps to a arc-place-arc sequence in CPN.

Two other concepts are important to understanding how the CPN language works. The first is the notion of a token. During the execution of a CPN model, a token represents the actual instantiation of a data element in the model. For example, a token in the C2 system architecture would be an instantiation of a track file during execution. A marking is simply the set of tokens at all of the places in the CPN model at a point in time during the model's execution. A marking defines the state of the CPN model [Jensen, 2009].

CPN Tools was used to develop the CPN model and to conduct all of the verification activities. CPN Tools is a freely available tool developed by the University of Aarhus in Denmark. CPN Tools has an intuitive Graphical User Interface and allows for specification of guard constraints and code segments using the CPN Markup Language, which is based on Standard Markup Language [Jensen, 2009].

### ***b. Modeling Assumptions***

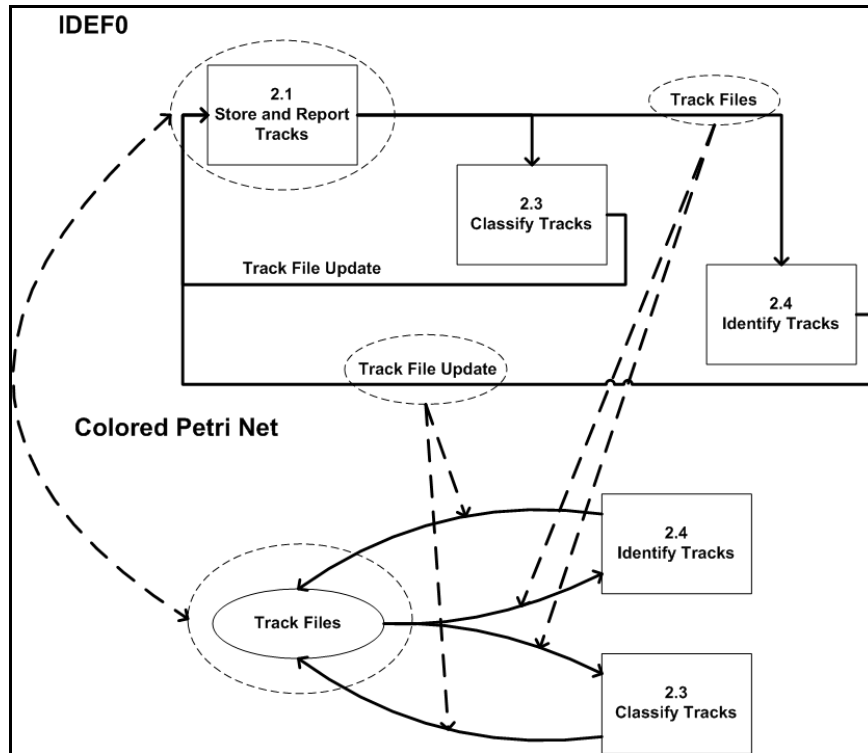
Several assumptions on the scope of the verification effort were made. Of highest importance, only the functional architecture (SV-4) was verified. Due to the mapping of the SV-4 System Functionality Description to the OV-5 Operational Activity Model, in the SV-5, no significant benefit would be achieved from a separate verification of the activity model.

The verification effort included only the target processing components. As a consequence, planning and display functions were not included in the verification. This includes the functions “1 Display Tactical Data”, “3.6 Develop Execution Guidance”, and their descendents. The rationale for this scoping decision was to exclude functions that provided a persistent input to the track processing functions, namely the planning functions, or did not have a feedback into the track processing functionality, specifically the display functions.

Similarly, external entities were modeled only if the architecture included a direct output-input relationship with the external entity that affected target processing. For practical purposes, this limited the external entities that were included to commercial ships, which receive queries from the C2 system and return a query response.

In order to keep the verification effort to a manageable size while still being able to assess the key elements of the architecture, verification was done using two concurrent targets, one commercial and one non-commercial. This allowed the verification effort to assess the proper concurrent execution of the SUW and MIO missions and to assess how well the architecture handles multiple, simultaneous targets.

The SV-4 was represented exactly as it appears in the architecture with only a single exception. The “Store and Report Tracks” function was implemented as a persistent data store in the CPN model. In the architecture, the “Store and Report Tracks” function serves the larger purpose of reporting track data to external command entities. However, as described above, that portion of the function is not within the scope of the verification, only the data store component remained. Figure 35 shows how the “Store and Report Tracks” function is implemented in the System Functionality Description and how it is implemented in the CPN model.



**Figure 35: Depiction of "Store and Report Tracks" function in SV-4 and CPN models**

The figure shows how the "Store and Report Tracks" function is implemented in the SV-4 as a function and as a place in the CPN model. In the CPN model, the "Store and Report Tracks" function is replaced by a "Track Files" place that serves as a track data store for other functions.

### *c. Verification Techniques*

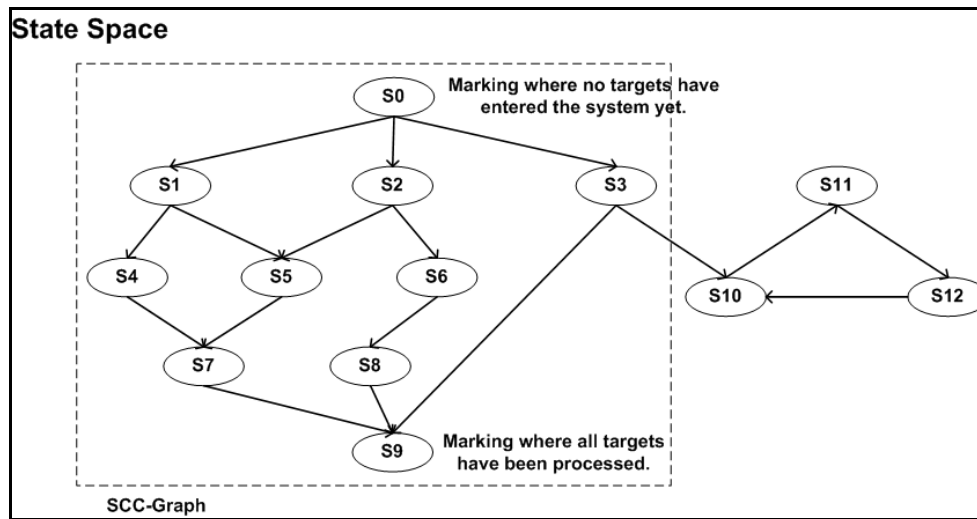
Two separate approaches were used during the verification of the architecture. First, simulation of the CPN model was used to initially assess whether the architecture executed properly. This technique used a step-by-step evaluation of the CPN model's execution to ensure that the commercial and non-commercial threats were handled properly and that the model consistently terminated with both targets processed. The CPN approach has the unique advantage over the use of COREsim in that the architecture can be assessed in its IDEF0 form and does not need to be converted into an EFFBD to support simulation.

The second verification approach was a state space analysis. The advantage of a state space analysis over a simpler simulation-based assessment is that the state space analysis checks all possible states that the model may assume. This gives the state space analysis the ability to identify logical flaws that may not manifest themselves during the execution of a finite number of simulation runs.



The state space analysis employs several distinct checks. The full state space, consisting of all possible markings of the system, is calculated. Based on the state space, three assessments are made: the Strongly Connected Components (SCC) graph is calculated, the home and dead markings are determined and any live or dead transitions are recorded. Each assessment is discussed in more detail below.

Two markings are in the SCC-graph if and only if they are mutually reachable. This means that a finite occurrence sequence exists between the markings. A SCC-graph that is smaller than the full State Space indicates the presence of cycles (infinite occurrence sequences) in the model [Jensen, 2009]. An infinite occurrence sequence in the model implies that it is possible that the model will never “finish” or reach a marking where there are no enabled transitions. If the architecture is correctly designed, the SCC-graph will be the same as the full State Space. Figure 36 gives an example of a SCC-Graph that is not the full state space.



**Figure 36: Example of SCC-graph that is a subset of the state space**

Note that the markings in the SCC-graph cannot be reached from the markings outside the SCC-graph. If the markings outside the SCC-graph are reached, the model will never “finish”.

The home markings and dead markings provide valuable information about the states in which the architecture has terminated. The home markings can be reached from any marking, meaning that from any possible marking of the system, the home marking can be subsequently reached. For our architecture, the marking where all targets have been processed should be reachable from any other marking and thus should be a home marking. The dead markings are states where no transition is enabled [Jensen, 2009]. This equates to the states where the

architecture has “finished”. If the architecture is correctly defined, the only dead markings should be the marking where all targets have been processed.

Finally, the live and dead transitions provide some additional information about the model. A live transition is any transition where an occurrence sequence exists from every reachable marking that contains the transition. Note that a live transition cannot exist if a dead marking exists. A dead transition is a transition where no reachable markings exist where the transition is enabled [Jensen, 2009]. Essentially, the transition can never execute. For a correctly defined architecture, neither live nor dead transitions should exist.

#### *d. Results*

During the simulation verification, ten runs were observed in step-wise execution without observed error. All runs terminated in the marking with all targets processed. The state space analysis also verified the architecture’s logical structure. The SCC-graph showed that the model has no infinite occurrence sequences. Additionally, the home marking and dead markings were identified and both correspond to the state with all targets processed. This means that the state with all targets processed is the only state reachable from all reachable markings and is the only state where no transitions are enabled (where the model is “finished”).

Since the state with all targets processed was identified as the sole dead marking, no live transitions exist. As well, no dead transitions were identified. Thus, there are no functions in the architecture that can never be executed.

In conclusion, the CPN verification results confirm that the architecture is logically complete and internally consistent. The architecture, as it is defined, has no infinite loops that prevent the successful processing of targets and will terminate only in the state where all targets have been processed.

## **B. COST ANALYSIS**

### **1. Background**

As previously discussed, and will be shown below, the architecture provided inputs to the basis of the cost analysis task. The Cost Analysis task was conducted in parallel with the M&S task under the assumption that the tasks were independent of each other. The Cost Analysis task

determined that in today's surface fleet, each major C2 system has its own unique training pipeline and capability upgrade activities that are part of the life cycle costs. Though they may have common missions, the C2 system functions, modes, and operator displays are different, requiring distinct training activities for each system. To field a capability upgrade across C2 systems, the upgrade is developed and tested for each C2 system, incurring costs for essentially the same work multiple times. Using a common C2 architecture across multiple platforms has the potential of avoiding the distinct training activity costs and repetitive costs for upgrade development. Cost analysis was conducted to test the surface navy acquisition community's assumption that a common C2 architecture and set of requirements would lead to systems that are less costly in terms of operator training and system capability upgrades and to quantify the potential savings.

## **2. Methodology**

### ***a. Historical Cost Data***

Initially, much effort was expended trying to obtain actual dollar cost values from DoD finance sources such as the Defense Cost and Resource Center maintained by the Office of the Secretary of Defense, the Navy Visibility and Management of Operating and Support Costs (VAMOSC) database, and Navy Budget Reports from the Assistant Secretary of the Navy's Financial Management and Comptroller site. However, these sources generally do not provide cost information decomposed to the C2 system level. For instance, the Defense Cost and Resource Center production costs are provided at the ship level. VAMOSC lists annual training costs for both Aegis and SSDS, but the costs are not decomposed to the specific C2 subsystem level. Navy Budget Reports list FY08 costs for specific capability upgrades for both Aegis and SSDS, but none are purely C2 upgrades. Without historical cost data at the C2 level, a meaningful parametric cost estimation relationship cannot be derived [Anderson, 2008].

### ***b. Training Hours***

Due to the lack of useable detailed data produced from this initial effort, the focus of the cost analysis was shifted to obtaining Aegis and SSDS training hours for the specific warfare area functions defined in the common C2 architecture. Hours spent training were used as a cost

metric instead of dollars. Aegis and SSDS C2 subsystem training hours were obtained from the Center for Surface Combat Systems (CSCS), which serves as the training site for both Aegis and SSDS operators [Parker and Salunga, 2009]. These metrics were traced directly back to the common C2 architecture by identifying the specific training courses and hours that cover the specific mission area C2 functions. Surface Warfare functions covered in both Aegis and SSDS curriculums of instructions were candidates for cost avoidance. The Navy could potentially condense these courses, thereby reducing the number of courses required, the number of instructors hours required, and the amount of training material preparation needed, resulting in more affordable training.

The seven-week Aegis Combat System Officer Track II course and the seven-week SSDS Combat System Officer course contain the majority of the surface warfare area mission training requirements [Parker and Salunga, 2009]. Curricula of instruction were obtained for both training courses from CSCS [Aegis Training and Readiness Center, 2009]. Aegis and SSDS subject matter experts provided assistance with course content where the Navy currently teaches subjects related to the surface warfare mission area functionality identified in the project architecture. The CSCS then provided calendars for each course that indicated the number of instruction hours planned per curriculum item. The number of instruction hours for the portions of the curriculum of interest was extracted from the calendars. Table 10 shows the results of the analysis. The columns indicate the functions of the C2 architecture created in this report and the rows identify the curriculum items. The intersecting cells indicate the number of hours of instruction for each function of the architecture. Curriculum items not related to surface warfare or the C2 architecture were not included in this analysis. An empty cell indicates no training of this function occurs in this curriculum item. The training hours extracted from the calendars for each curriculum item are shown in the far right hand column. The hours were distributed evenly to the relevant intersecting cells as an estimate of the instruction hours per function. Total instruction hours per C2 function were calculated for each course. The bottom row shows the smaller of the Aegis and SSDS training hours per function and represents the potential training hours that could be saved if these C2 systems had a common architecture for surface warfare mission functions.

**Table 10: C2 Training Hours**

This table shows the C2 training hours from the Aegis and SSDS Combat Systems Officer courses allocated to the common architecture functions. The hours per function are totaled and compared to determine potential duplicative training hours

	PERFORM COMMAND AND CONTROL FOR SURFACE WARFARE AND MIO (based on 09 March 2009 architecture)																												
	1.0 Display Tactical Data					2.0 Perform Track Management							3.0 Conduct Combat Control															4.0	
	1.1 Provide Tactical Display Configuration Options	1.2 Display Track Data	1.3 Display Engagement/VBSS Status	1.4 Display Sensor Status	1.5 Display Command Data	2.1 Store and Report Tracks	2.2 Form Tracks	2.3 Classify Tracks	2.4 Identify Tracks	2.5 Correlate/Decorelate Track	2.6 Associate Bearings/Files to Tracks	2.7 Manage Track Numbers	3.1 Assess and Prioritize Threats			3.2 Determine Weapon Target Pairing Options			3.3 Issue Engagement Order	3.4 Query Ship	3.5 Issue Boarding Order	3.6 Develop Execution Guidance			3.7 Assess Engagement	4.0 Report Status	Training hours from C2CS		
													3.1.1 Identify Threats	3.1.2 Prioritize Threats	3.1.3 Identify Actions Required for Each Threat	3.2.1 Estimate Engage Effectiveness	3.2.2 Identify Engagement Conflicts	3.2.3 Compile Weapon Target Pairing Options				3.6.1 Develop Engagement Guidance	3.6.2 Develop Sensor Plans	3.6.3 Develop Track Management Policy					
<b>Aegis CSO Trk II</b>																													
Description of C&D System	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6				0.6	0.6	0.6	0.6	0.6	14	
Combat Display Console	2.6	2.6	2.6	2.6	2.6																							13	
Track State						0.3	0.3	0.3	0.3	0.3	0.3	0.3												0.3				2.5	
Special Point & Geometric Entry	0.3	0.3					0.3																					1	
ID Supervisor													1.3											1.3				2.5	
Combat System Coordinator															0.7	0.7	0.7	0.7	0.7							0.7	4		
Missile Modes/Policy Engage															0.8			0.8	0.8				0.8					3.0	
Maneuver Control State	2.0																											2.0	
Navigation Data Entry State	2.0																											2.0	
Warfare Coordination															1.8	1.8		1.8					1.8			1.8	9.0		
AEGIS Display System (ADS)	0.3	0.3	0.3	0.3	0.3																							1.5	
ADS CO & TAO		0.9	0.9	0.9	0.9										0.9	0.9			0.9									6.5	
Non Weapons Doctrine								2.0	2.0																			4.0	
CEC Composite ID								0.4	0.4	0.4		0.4												0.4				2.0	
Weapons Selection Doctrine																1.8			1.8	1.8			1.8					7.0	
Anti Surface Warfare							0.2	0.2	0.2				0.2	0.2	0.2	0.2	0.2	0.2	0.2							0.2		2.0	
Pre-planned responses																0.5							0.5					1.0	
Threat Response Timeline													0.3	0.3	0.3													1.0	
Combat ID								0.5	0.5																			1.0	
Automated ID								1.0	1.0																			2.0	
<b>Aegis Totals</b>	<b>7.8</b>	<b>4.7</b>	<b>4.4</b>	<b>4.4</b>	<b>4.4</b>	<b>0.9</b>	<b>1.4</b>	<b>5.0</b>	<b>5.0</b>	<b>1.3</b>	<b>0.9</b>	<b>1.3</b>	<b>2.3</b>	<b>3.8</b>	<b>7.5</b>	<b>1.4</b>	<b>3.2</b>	<b>3.9</b>	<b>4.9</b>	<b>0.0</b>	<b>0.0</b>	<b>5.4</b>	<b>0.6</b>	<b>2.5</b>	<b>0.8</b>	<b>3.1</b>	<b>81.0</b>		
<b>SSDS CSO</b>																													
General Description	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2				0.2	0.2	0.2	0.2	0.2	4.0	
Battle Management Organization																							0.3	0.3	0.3	0.3		1.5	
CO's Battle Orders														0.3	0.3	0.3			0.3			0.3						1.5	
Sensors				5.3		5.3	5.3																5.3					21.0	
Electronic Warfare								1.4				1.4	1.4			1.4			1.4									7.0	
External Communications																				1.0							1.0	2.0	
Engagements																1.6	1.6	1.6	1.6			1.6					1.6	9.5	
States, Modes & Alerts	0.7	0.7	0.7	0.7	0.7																							3.5	
SSDS Display	1.0	1.0	1.0	1.0	1.0																							5.0	
CEC						0.5	0.5	0.5	0.5	0.5	0.5	0.5												0.5				4.0	
Decision Aids & Graphic Overlays	0.8	0.8																										1.5	
Engagement Dootrine													0.4	0.4	0.4	0.4	0.4	0.4	0.4			0.4						3.0	
SSDS ID								1.0	1.0			1.0	1.0											1.0				5.0	
SUW/Scenario 3 - 6							0.3	0.3	0.3				0.3	0.3	0.3	0.3	0.3	0.3	0.3			0.3			0.3			4.0	
C2 Assets					0.5																						0.5	1.0	
Casualty Ops																			0.5			0.5					0.5	1.5	
Engagement scenarios 4 - 10			1.8	1.8											1.8	1.8	1.8	1.8	1.8			1.8						16.0	
<b>SSDC CSO Totals</b>	<b>2.6</b>	<b>2.6</b>	<b>3.6</b>	<b>8.9</b>	<b>2.4</b>	<b>5.9</b>	<b>6.2</b>	<b>3.4</b>	<b>2.0</b>	<b>0.7</b>	<b>2.1</b>	<b>3.1</b>	<b>2.1</b>	<b>2.9</b>	<b>2.9</b>	<b>5.6</b>	<b>4.2</b>	<b>4.2</b>	<b>6.4</b>	<b>1.0</b>	<b>0.0</b>	<b>5.2</b>	<b>5.7</b>	<b>1.9</b>	<b>0.7</b>	<b>3.7</b>	<b>91.0</b>		
<b>Possible Common Hours</b>	<b>2.6</b>	<b>2.6</b>	<b>3.6</b>	<b>4.4</b>	<b>2.4</b>	<b>0.9</b>	<b>1.4</b>	<b>3.4</b>	<b>2.0</b>	<b>0.7</b>	<b>0.9</b>	<b>1.3</b>	<b>2.1</b>	<b>2.9</b>	<b>2.9</b>	<b>1.4</b>	<b>3.2</b>	<b>3.9</b>	<b>4.9</b>	<b>0.0</b>	<b>0.0</b>	<b>5.2</b>	<b>0.6</b>	<b>1.9</b>	<b>0.7</b>	<b>3.1</b>	<b>Total 59.0</b>		

### *c. Capability Upgrades*

System complexity was investigated as a comparative measure of cost for a C2 system capability upgrade. System interface information could be used to determine the complexity of a system. As an indicator for system complexity, the number of interfaces a system has, or the number of message types a system passes across an interface, could provide quantitative values to compare across different systems. In theory, the more complex the system, the more costly it would be to update [Turney, 2000].

This type of information could be used to assess the level of complexity of a system. With access to system interface documents, interface variables such as quantity of interfaces and quantity of message types across each interface could be used as values to compare the relative complexity between multiple systems. A thorough, quantitative analysis of this kind of information requires access to some classified sources for a complete definition of all interfaces. In order to keep the report unclassified, the complexity versus upgrade cost aspect was not pursued..

### **3. Cost Analysis Conclusions**

Table 10 shows a total of fifty-nine training hours from both the Aegis and SSDS curriculum that could potentially be condensed if a common C2 system for surface warfare was used. Fifty-nine hours is 25% of the total (including non C2) instructional hours from each course. From a future C2 system perspective, this is a potential cost avoidance of fifty-nine training hours in the surface warfare mission alone by using a common C2 system across platforms.

Note this data shows no common hours for the MIO unique functions Query Ship and Issue Boarding Order. MIO is not part of the Aegis Combat System Officer course, nor is MIO part of the Aegis curriculum at CSCS [Parker and Salunga, 2009]. One recommendation for further study (using the same training hour metric) would be to explore other warfare areas including MIO. It is also quite possible that additional surface warfare training hours would be considered common. This analysis only considered one course for each C2 system that the CSCS staff considered to contain the majority of C2 training. Broadening this approach to other mission areas could support the general notion that a mission driven system functional

architecture will result in functionality across systems that would be similar as to ease the training requirements across systems.

This cost analysis supports the surface navy acquisition community's assumption that a common C2 system will reduce the cost of training. However, due to the lack of open source information on Aegis and SSDS C2 interfaces and message types, a conclusion on the assumption that common C2 would reduce the cost of capability upgrades could not be reached. A second recommendation for further study is to examine the availability of the interface information and the validity of using interface complexity as a cost metric.

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## **V. SUMMARY AND AREAS FOR FURTHER STUDY**

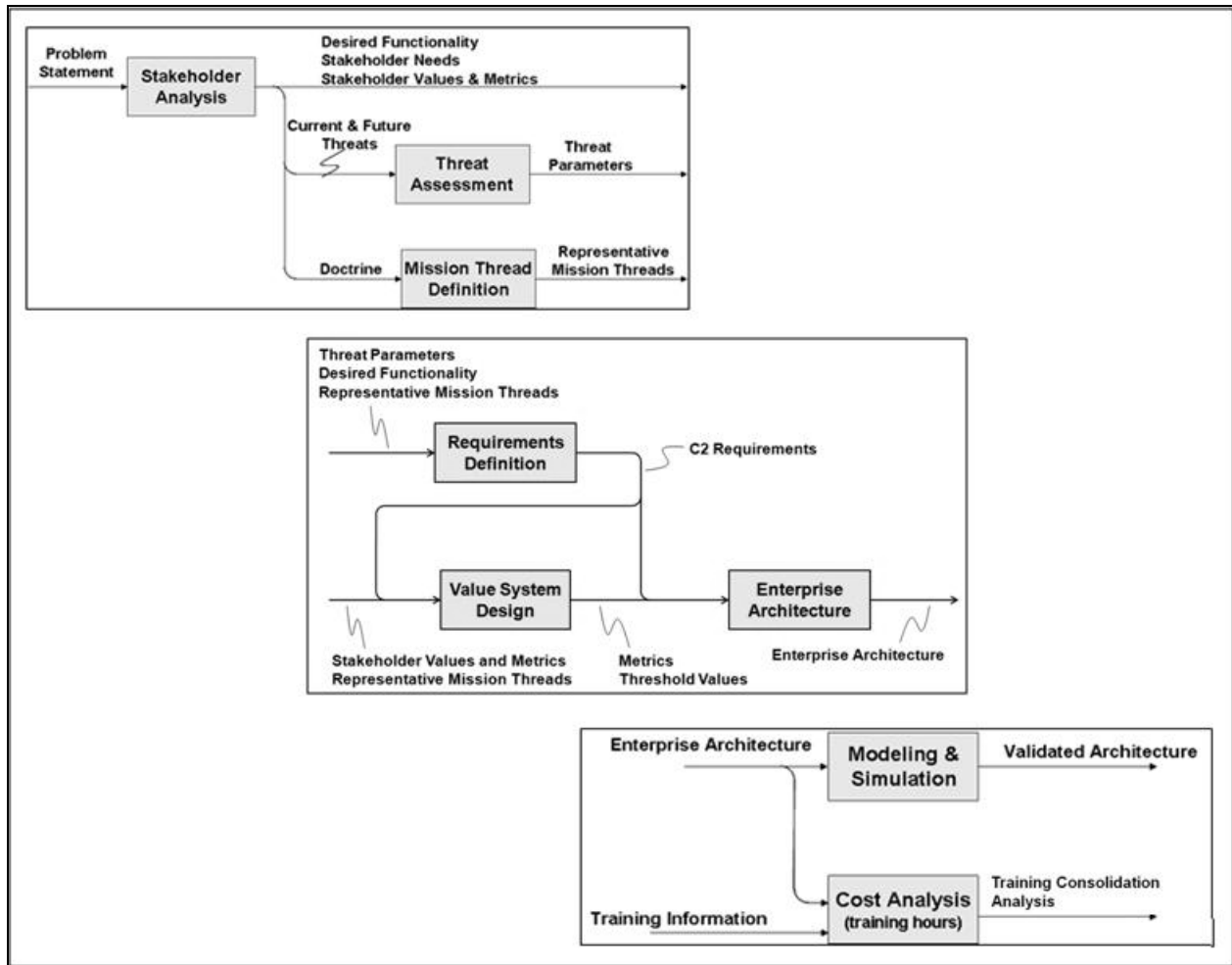
### **A. SUMMARY**

The objective of this report was to test the assertion that a common architecture would reduce combat system lifecycle costs. The project used a three phase Systems Engineering model (Figure 37) to gather stakeholder inputs, develop a common architecture, and then investigate if the common architecture can support training cost savings. The products from each successive phase served as inputs for the follow-on phases.

Through this process, a common architecture for a generic naval warship C2 system was developed, using two mission threads, SUW and MIO, as a basis for the functionality of the system. The system functionality identified in the architecture was used to identify course material from two current combat systems that could be combined if a combat system was developed using a common architecture. The cost analysis findings indicate that potential savings in training hours could be realized if a common architecture were to be developed.

There were three steps in the Needs Analysis Phase: Stakeholder Analysis proved to be the foundational step in clarifying the problem statement. Primarily through review of joint and naval service doctrine, this step revealed a conceptual functionality of the purpose of a C2 system and desired characteristics of a C2 system. Another important concept gained during this step was that a C2 system includes software, hardware, and people. This concept was a key contributor leading into the mission thread development. The stakeholder interviews conducted during this step validated some of the information gathered in the document review, giving the analysis a “real person” perspective.

The purpose of the threat assessment was to gain an understanding of the types of vessels, and their threat characteristics, that the C2 system might encounter. Extensive open source research was conducted in this area and the results of the research contributed to C2 requirements development and analysis. The threat assessment could also be valuable in defining sensor characteristics such as range, search rate, and resolution. However sensor systems and specific timing requirements were beyond the scope of the project.



**Figure 37: Summary of Project Systems Engineering Process**

This Figure summarizes the three phase systems engineering process used to develop the enterprise architecture and to estimate potential cost savings achieved by using a common architecture. Outputs from each phase provided inputs to follow-on phases.

Like the Stakeholder Analysis, the Mission Thread definition also provided foundational information for the project. Two mission threads built upon the information gathered in the Stakeholder Analysis. This step translated the high level concepts into a more detailed level of activities and interactions, which were then used to support requirements and architecture development. Another key aspect of this step was problem scoping. The mission threads delineated what was inside the system boundaries, and what was outside the system boundaries. For example, sensor characteristics were outside of the system boundary, as discussed above. People, on the other hand, as it was learned during the Stakeholder analysis, were inside the system boundary.

The next phase, Functional Analysis, included three steps: Requirements Definition, Value System Design, and Enterprise Architecture. The Requirements Definition produced written statements to describe the characteristics of the C2 system. This step was the link between the concepts in the Needs Analysis and the system functionality depicted in the architecture. This step provided the quality control that the functions in the architecture correctly supported the concepts of the Needs Analysis phase. Through traceability from the Needs Analysis concepts to the functions documented in the architecture, the requirements definition step ensured that the needs analysis concepts were being addressed and also that the architecture did not include unnecessary functions.

The Value System Design identified quantitative values or ranges that were included as attributes of the requirements. These values would be useful during design and development when the systems are actually being built; defining how well the systems need to perform. The values also provide a benchmark during testing, as a measure of how well the system performs. However, the contributions of the Value System Design step was negligible for the scope of this project, which was the high level definition of requirements and architecture to support training cost evaluation.

The Enterprise Architecture step described the functionality and interactions of the C2 system, working within the boundaries established by the mission threads and the requirements. The architecture further described the functionality of the system, and also how the functions would interact with each other. A key objective of this step was to describe the functionality of the system. This system functionality was then used in the development of the end state of this project – the training cost analysis.

The final phase of the project was Modeling and Analysis. This phase included two unrelated steps, validation of the architecture and cost analysis. Since both steps involve modeling and analysis, they were included in the same phase. However, there is risk that the independent steps are misinterpreted as being dependent upon each other. The purpose of the Modeling and Simulation step was to validate that the functions in the architecture were organized in a logical and executable manner; for example an architecture that classifies a contact before it detects it would not be realistic or executable. The model and simulation step validated that the organization of the functional architecture was reasonable.

The Cost Analysis step provided the end product for this project – an assessment of whether an enterprise architecture could result in training cost savings. The step used a matrix to compare the functions in the project architecture to known topics being taught in current, independent C2 system courses. The unions between functions and course topics identified potential areas of overlap for the two training courses evaluated. The project used course hours as the comparison metric. Actual dollar cost was considered as a metric option but rejected because of the greater amount of variability associated with training costs. Training hours was considered to be a more metric for comparison. The analysis concludes that the design of a common C2 system, derived from an enterprise C2 architecture could support training cost savings.

Overall, the project team learned that it is possible to design a functional architecture based upon some high-level concepts and needs. It is critically important to conduct research in order to understand stakeholder needs. Written requirements add clarity and definition to the initial problem concept. Architecture products add fidelity and increase the understanding of the initial need. The systems engineering process used in this project does help move the Navy towards an enterprise architecture approach to achieve cost savings.

## **B. AREAS FOR FURTHER STUDY**

This report acknowledges the limited scope of this project. Areas for further study were identified throughout the development of this study and are summarized below.

- **Further mature the requirements and architecture developed in this report:** Using the process identified in this report, work could be continued to add to the fidelity of the existing requirements and architecture set. Additional requirements and architecture products could be developed. Quantitative values could be refined and added to the requirements. These same quantitative values could then be incorporated into the architecture and performance tested.
- **Expand the architecture to additional mission areas:** Additional mission threads could be developed (for example, conduct air warfare). Associated requirements and architecture products could then be developed and added to these existing products.
- **Conduct additional cost analysis:** Cost analysis in the training area could be expanded in several ways, including: investigation of additional training methods,

adding actual cost values to the existing metrics identified in this report, and investigating training hours for additional mission areas. Other areas for further study include the investigation of additional cost metrics, maintainer documents, spare parts, logistics infrastructure and capability upgrade comparisons.

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## **APPENDIX A: PROGRAM MANAGEMENT PLAN**

### **INTRODUCTION**

This is the project management plan (PMP) for the Naval Postgraduate School (NPS) Masters of Science in Systems Engineering (MSSE) program capstone project Cohort 311-074. The PMP was prepared by the Naval Surface Warfare Center (NSWC) Corona Division and Dahlgren Division team. The project is an enterprise requirements and architecture (ER&A) initiative.

### **Problem Statement**

Across the Surface Navy Enterprise, each new ship class implements a new command and control (C2) design for the combat system with a unique set of system requirements and associated architecture. This leads to individual platform development efforts, operations and support requirements, and training pipelines which complicates interoperability and incurs additional costs to the Navy. There is a need to define a superset of requirements and a common enterprise command and control architecture that can be implemented by multiple surface ship platforms. A single architecture, defining the functionality required and allocating those functions to system elements, would allow for a concept of modular sensor and weapon interface elements. If the architecture is reusable and scalable to future ship classes, a potential for lifecycle cost savings exists.

### **Project Proposal**

Surface combatant platforms commonly have battlespace awareness as well as command and control (C2) for core ship self-defense and area-defense missions in the area of surface warfare (SUW). The NSWC team will use Department of Defense Architecture Framework (DoDAF) products to define an enterprise-level C2 architecture that is independent of existing systems or platforms. The architecture developed will support functionality normally performed by guided missile cruisers (CG), guided missile destroyers (DDG), and guided missile frigates (FFG), with the expectation that the concepts and processes developed in this project can be scaled to broader surface platform applications. The DoDAF products will be based upon two representative mission threads and associated C2 functionality.

The NSWC team has identified two mission threads to be assessed, one of a combat nature and one of a non-combat nature:

- Conduct SUW - Detect, track, identify, report, support engagement decisions, and maintain status on surface contacts.
- Conduct maritime interception operations (MIO) – Exchange information during a MIO event to support battlespace awareness and decision-making.

The above mission threads will be addressed in the architecture and developed to exercise the following C2 functionality [DoDCCRP, 2008]:

- Common Tactical Picture (CTP)
  - The capability for all participating units to display the same tactical picture as the unit that detects the target.
  - The ability to accurately report contact identification, heading, position, and speed.
- Common Operational Picture (COP)
  - The ability to follow a set doctrine that is common among all units.
  - The ability to accurately report ship and strike group status to higher-level command organizations and to receive and maintain force-level status.
- Tactical C2
  - The ability to follow the Navy or Joint Task List for the following critical operational components: detect, track, identify, report, engage, and manage data.



## **Risk Management**

The Project Management team will be responsible for risk analysis, risk mitigation and risk tracking. Project members will contribute to risk identification. Risk analysis will follow a standard likelihood and consequence assessment and use the risk rating matrix in the Risk Management Guide for DoD Acquisition. Due to the constraints of the academic calendar and the absence of funding for the effort, all risks are to performance. In other words, the quality of the product is what is at risk, not when it will be delivered or at what cost.

Limited options exist for risk mitigation within the structure of the Capstone project, therefore, avoidance of risk may require a renegotiation of the PMP. Control of risk by adding personnel or maintaining parallel approaches will be severely constrained by the extent of existing tasking. There is no external entity onto which to transfer risk. This makes risk assumption the default mitigation approach. If risks are realized such that the NSWC team will not be able to satisfy the PMP, the risk will be mitigated via a renegotiation of the PMP with a reduced scope in the risk area.

Risk status will be reported by the Program Management team at each Integrated Product Review (IPR). If required, risks will be reported in the interim periods to the advisors and project stakeholders by the Program Management team. The two major, initial risks have been identified and assessed, summarized in Table 1.

**Table 1: Risk Management Matrix**

<b>Risk ID</b>	<b>Risk Name</b>	<b>Description</b>	<b>Likelihood</b>	<b>Consequence</b>	<b>Risk Rating</b>
R001	Cost Analysis Data	Not all data required to complete the cost analysis may be available.	Near Certainty (5)	Minor (2)	Yellow
R002	M&S Data	Not all data required to complete the performance analysis may be available.	Highly Likely (4)	Moderate (3)	Yellow

## **Vision**

The NSWC team's vision is to create an enterprise-level C2 architecture for CGs, DDGs, and FFGs, with the expectation that the architecture can be generalized and utilized by other platforms. The core architecture addresses two diverse mission threads, a combative and non-combative thread. This combination of threads will allow the team to work through and identify several of the issues that may not be realized through an otherwise similar mission thread selection. Ultimately, the enterprise solution developed will act as a foundation for future Navy application. This foundation will be used to save the Navy integration lead time, minimize redundant logistic support pipelines, and reduce the need for stovepipe training methods. Further, this architecture will lead to a cross-trained sailor and a more effective and unified Fleet.

## **End-State**

The NSWC team will develop a superset of C2 requirements for multiple platforms based on the mission threads to conduct SUW and MIO. The team will develop an enterprise-level C2 architecture and will provide DoDAF products based on the mission threads and the superset of C2 requirements. The NSWC team will perform a cost analysis to establish potential cost differences with current configurations of C2 architecture. The final report will document the methodology and the process used to identify the superset of requirements, providing a traceable and repeatable means for developing other C2 architectures for differing mission threads.

## **PROJECT PARTICIPANTS**

### **Team Members**

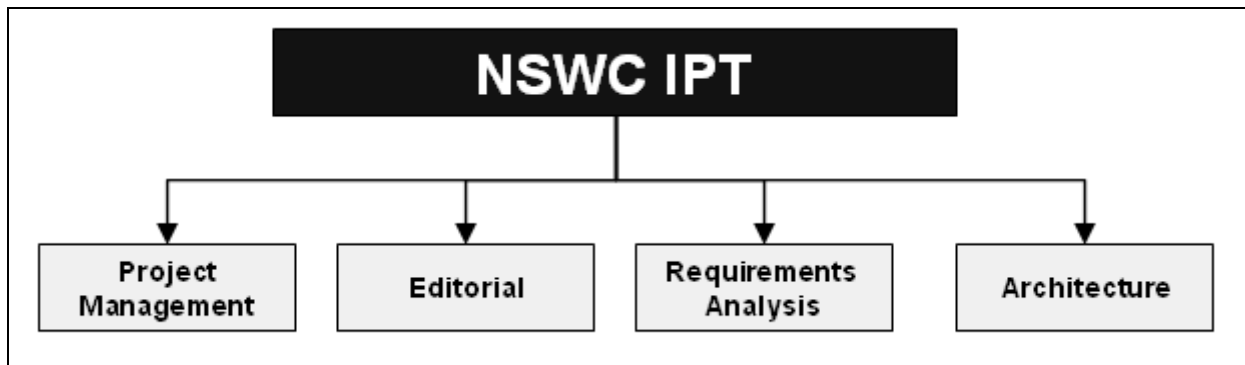
The ER&A capstone project team is composed of sixteen students enrolled in the MSSE with a systems development focus distance learning program at NPS in Monterey, California. The team members and their respective organizations are listed in Table 2.

**Table 2: NSWC MSSE Team Members**

<b><u>NSWC DAHLGREN</u></b>	<b><u>NSWC CORONA</u></b>
Joanna Beger-Mason	Elvis Acosta
Harry Donovan	Jordan Barta
Matt Eak	Llewellynn Galace
Dave Finley	Andrina Maurseth
Brian Jones	Lee Metz
Lesley Painchaud	Reshma Suchit
Josh Pepper	
Rob Tidwell	
David Yu	
Bob Zanella	

### **Team Organization**

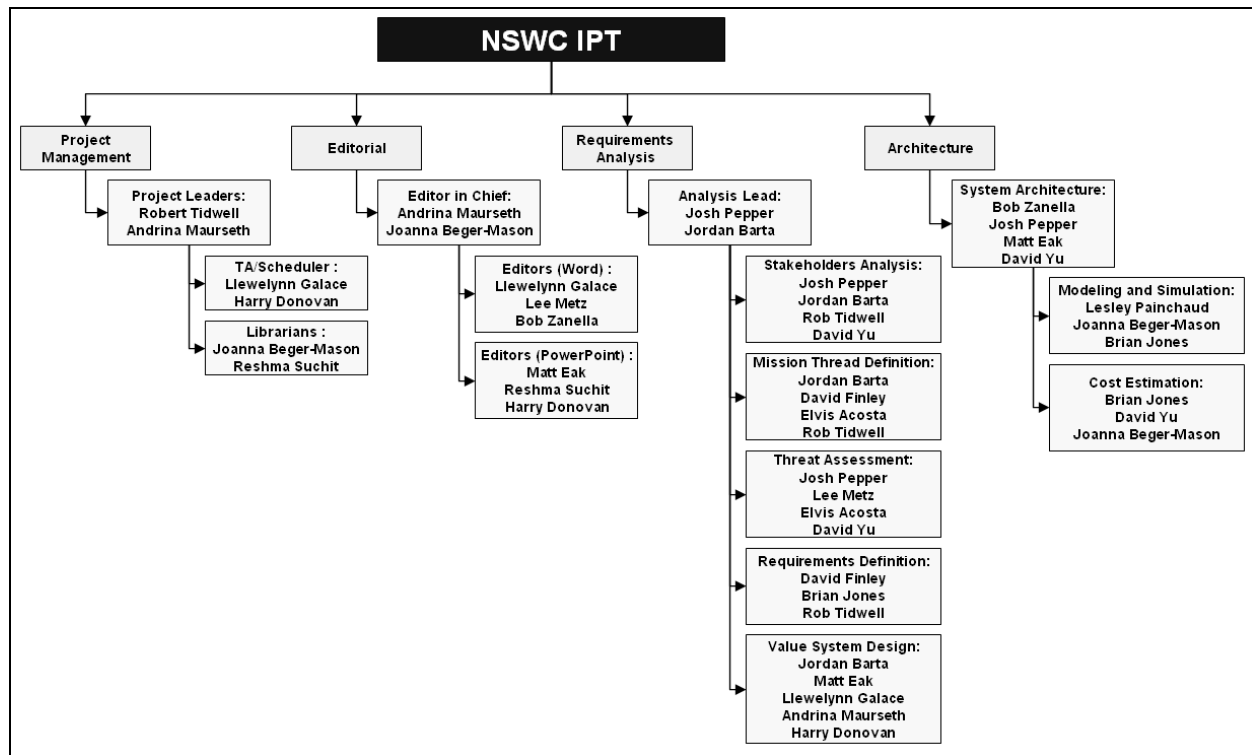
The NSWC project team is organized into four working groups (WG) as shown in Figure 1. Each working group will manage specific roles and responsibilities, which will be discussed in detail in subsequent sections. As a collective, the working groups collaborate to form the NSWC integrated product team (IPT) to deliver the final project report and presentation.



**Figure 1: NSWC IPT Structure**

### **Roles and Responsibilities**

The ER&A effort will be integrated organizationally to accommodate the assigned technical authorities and engineering specialties commensurate with the requirements of the project. The NSWC team has identified key working groups in an effort to assign points of contact and accountability for all major tasks. Working group personnel and responsibilities are addressed in the subsequent section. Figure 2 identifies the leads and members of the working groups.



**Figure 2: NSWC Working Group Structure**

## Project Management Working Group

The Project Management group coordinates the overall activities of the NSWC project team. The project management working group consists of the Project Leaders, Technical Assistants (TAs) Schedulers, and Librarians.

- **Project Leader**

The project leader is responsible for overall management of the capstone project. There is a leader at each NSWC site (Dahlgren and Corona) to manage and execute the project according to the project plan and to maintain a balance between the technical, schedule, and administrative requirements of the project and organization of working groups. The project leader responsibilities include: facilitate group meetings and information exchange, monitor and guide the overall project activities, foster team member participation, and promote collaboration among the working groups.

- **Librarian**

The Librarian is responsible for cataloguing reference material, tracking and verifying sources of research, and ensuring completeness of references for project deliverables. The Librarian will coordinate Blackboard document control efforts with the working group leaders.

- **Schedulers/Technical Assistants (TA)**

Schedulers/TAs are responsible for assisting the project lead with administrative tasks, recording and distributing meeting minutes, scheduling either ElluminateLive! or Defense Connect Online (DCO) sessions, maintaining the master schedule and plan of action and milestones (POA&M), and creating Blackboard repositories for the team's various documents.

## **Editorial Working Group**

The purpose for this working group is to ensure that all deliverable documents comply with the *SE Writing Standards* and to ensure that the documents are comprehensive and complete. The editorial WG consists of an editor-in-chief, report editors, and presentation editors.

- **Editor-in-Chief**

The primary responsibility of the editor-in-chief is to review and edit all deliverable documentation. The editor-in-chief delegates responsibilities to the other members of the editing staff as necessary. The editor-in-chief will also work with the Librarian to ensure that all sources have been cited appropriately.

- **Report Editor**

The report editors will assist the editor-in-chief with the reviewing and editing of report sections, ensuring that the content is consistent with the presentation material, and ensuring content meets *SE Writing Standards* and milestone requirements.

- **Presentation Editor**

The presentation editors will assist the Editor-in-chief in reviewing and editing of presentations, ensuring that the content is consistent with the report material, and ensuring the content meets *SE Writing Standards*, milestone requirements, and Integrated Product Review (IPR) requirements.

## **Requirements Analysis Working Group**

The requirements analysis working group coordinates the efforts of the following working groups: stakeholder analysis, mission thread development, threat assessment, requirements definition, and value system design. Each of these working groups will aid in the formulation of a comprehensive set of requirements.

- **Stakeholder Analysis Working Group**

The stakeholder analysis working group is responsible for identifying clients (and organizations) that will benefit in the success of the ER&A being developed. Analysis includes identifying the client's needs and objectives, which will be used to translate into functional requirements. The lead will maintain contact with the stakeholder(s) and will coordinate with the advisors to solicit information.

- **Mission Threads Working Group**

The mission threads working group is responsible for researching and establishing the mission threads that are required for ER&A.

- **Threat Assessment Working Group**

The threat assessment working group is responsible for conducting an analysis of threats to naval platforms relevant to the selected mission threads.

- **Requirements Definition Working Group**

The requirements definition working group is responsible for translating stakeholder needs and objectives into ER&A functional requirements and tracing these requirements to the applicable system elements.

- **Value System Design Working Group**

The value system design working group is responsible for creating a value tree (a composite of the stakeholder and functional analyses) and identifying metrics, such as performance measures. The lead will coordinate with the stakeholder analysis and requirements definition working groups to ensure the model reflects the stakeholders' needs and objectives and functional requirements and will provide the metrics to the Modeling & Simulation (M&S) working group.

### **Architecture Working Group**

The architecture working group is responsible for overseeing and coordinating the development of the architecture for the enterprise requirements. This group will participate in preparation of a high-level system and requirements definition and coordinate with the project leads and modelers on execution of all technical aspects of the architecture. The architecture group will also prepare and submit an ER&A integration report to the project leads, which will identify interfaces between systems, subsystems, and platforms that need to be included as part of ER&A.

- **Modeling & Simulation Working Group**

The modeling and simulation working group will identify M&S tools and assist other working groups in developing and conducting M&S to evaluate the effectiveness of the combat system command and control architecture.

- **Cost Estimation Working Group**

The cost estimation working group will ensure that all cost categories are considered and that a cost-benefit analysis is completed for decisions in the program. The cost analysis includes the evaluation of trade-offs that reduce cost while still meeting all operational requirements.

### **Advisors**

The ER&A capstone project lead advisors are Mr. Gregory Miller and Prof. Paul Montgomery, faculty members of the Department of Systems Engineering at NPS. The ER&A capstone project support advisor is Dr. Emmett Maddry, a senior leader at NSWC Dahlgren Division.

## **Stakeholders**

The roles of the stakeholders will be to evaluate the merit of the project and provide direction to help guide the development efforts. The primary activities of the stakeholders will be to provide informal feedback to the students throughout the project and provide formal feedback by participating in the three project reviews. If conflicting guidance or objectives are received from stakeholders, the team will negotiate with the stakeholders to attempt to achieve a consensus. Given the limited performance period of this project, the team (with staff advisor concurrence) will choose a solution to implement for the project and document the discrepancy of non-concurrence in the final report. At this time the NSWC team is still in the process of identifying stakeholders and thus far, three stakeholders at NSWC Dahlgren have been identified, Mr. Gil Goddin, Mr. Tim Neel, and Mr. Doug Haas.

Mr. Gil Goddin is a Senior Systems Engineer in the Warfare Systems Department Warfare Systems Engineering and Analysis Division. He is the Warfare Systems Definition Branch head and is currently the enterprise Systems Engineer who works with Program Executive Office (PEO) Integrated Warfare Systems (IWS) to define commonality across platforms for combat system design.

Mr. Tim Neel is a Senior Combat Control Systems Engineer in the Warfare Systems Department Combat Control Division. Mr. Neel has extensive experience leading C2 and combat system architecture development efforts. He is currently involved in three distinct C2 and architecture efforts.

Mr. Doug Haas serves as the Senior Technical Advisor to the Warfare Systems Department Combat Control Division and supports the department for combat control systems engineering matters regarding the continued advanced development of surface combatants. He has a broad working knowledge of the architecture, requirements, performance, capability and limitations of the individual combat control systems providing this functionality.

The NSWC team has identified three other potential stakeholders at NSWC Dahlgren; however



the team has not yet confirmed that these stakeholders will be able to participate. The team will also attempt to identify and engage user and resource sponsor stakeholders.

## **MANAGEMENT PROCESS**

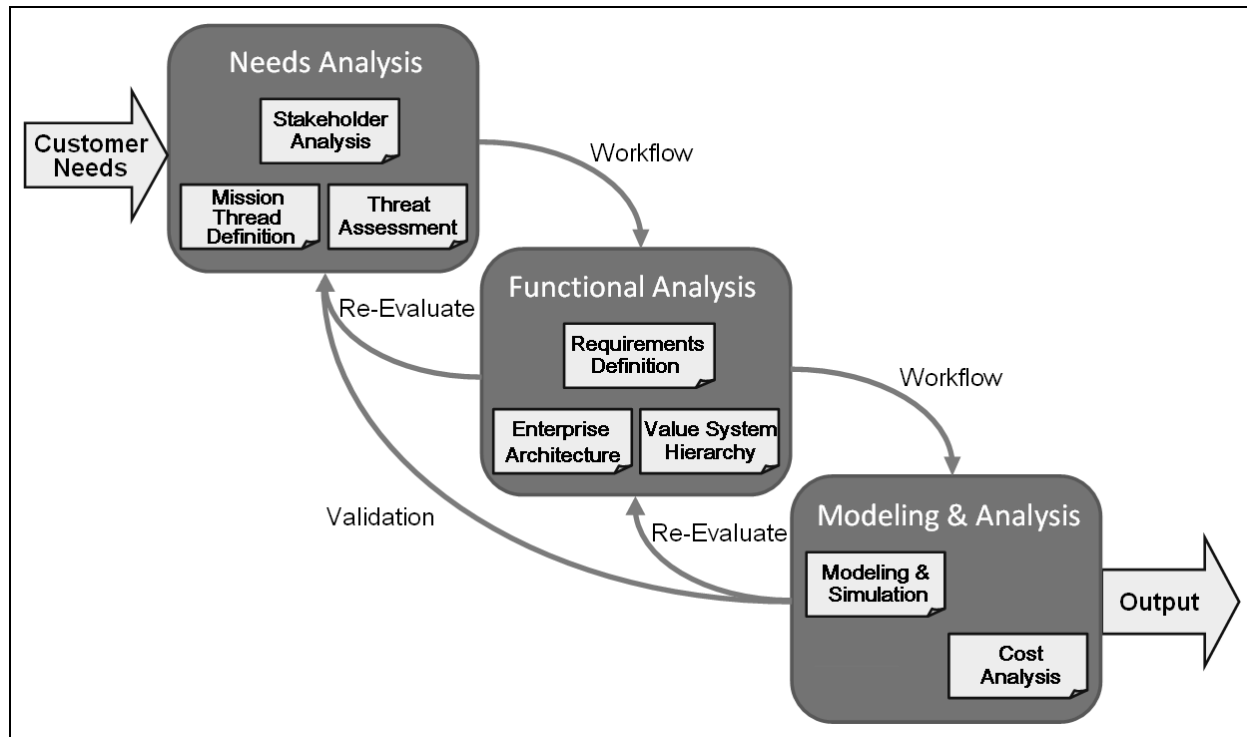
### **Systems Engineering Design Process (SEDP)**

The NSWC team will employ a tailored systems engineering design process (SEDP) illustrated in Figure 3 to establish a C2 enterprise architecture and requirements. This process is an adaptation of the systems engineering process published in System Engineering Fundamentals from the Defense Acquisition University in January of 2001 was tailored to reflect the actual phases planned for this Capstone Project.

The process begins with the Needs Analysis phase, where the problem statement is refined to understand the stakeholders and their actual needs and expectations. This phase will also describe the mission threads that the team identified as part of the project proposal and identify the threat against which the C2 architecture and requirements must perform. These tasks will occur in parallel.

The Functional Analysis phase will define the system-level requirements, followed by a functional architecture for the C2 aspects of the platform and a value system design by which the architecture will be evaluated. As the team works through this phase, the team will return to the tasks performed in the Needs Analysis phase to determine whether stakeholder input is needed for clarification, whether threads are adequately defined, or whether threats are fully established.

The Modeling and Analysis phase will provide simulation results to support and further define the metrics identified during the Functional Analysis phase. The team will also perform a cost analysis to identify potential cost differences in current configurations. Similar to the previous phase, the team will re-evaluate the requirements, architecture, mission threads, and threats as appropriate and will contact the stakeholders to determine whether the project remains on task with the stakeholders' needs. This project will result in a documented process for developing a scalable enterprise requirements and architecture set, as well as specific requirements and architecture sets to support the identified project mission threads. The following sections specify the tasks, input and output, and tools required for the NSWC team to perform the defined tasks.



**Figure 3: NSWC Tailored Waterfall Process**

## Needs Analysis Phase

- Task 1 Stakeholder Analysis**

This task will identify the applicable stakeholders, identify key stakeholder guidance, and identify the guiding principles for further needs analysis. Stakeholder guidance includes strategy documents, doctrinal publications, tactical publications, and tactical task lists.

Inputs: Problem statements

Tools: Publication review, interviews with stakeholders

Outputs: Description of stakeholder needs and guidance, desired measures to be used in Value System Design phase

- **Task 2 Mission Thread Definition**

This task will research and establish the mission threads that are required for ER&A. This task will define the details of the SUW and MIO mission threads.

Inputs: Problem statements, stakeholder analysis, Navy doctrine and publications, mission thread identification

Tools: Affinity diagrams, research, mission threads, context level extended functional flow block diagrams (EFFBDs)

Outputs: Mission thread definition, context diagram

- **Task 3 Threat Assessment**

This task will identify the potential threats to U.S. Navy platforms during the conduct of SUW and MIO missions across the spectrum of operating areas and conventional and non-conventional threat systems.

Inputs: Problem statement, stakeholder analysis, mission thread definition

Tools: Research

Outputs: Threat assessment

## **Functional Analysis Phase**

- **Task 1 Requirements Definition**

This task will translate stakeholder needs and objectives into ER&A functional requirements and decompose these requirements into a functional architecture.

Inputs: Stakeholder analysis, mission thread definition, threat assessment, context diagram

Tools: CORE

Outputs: Initial requirements hierarchy, functional hierarchy, operational activity diagram (OV-5), enterprise requirements, requirements traceability

- **Task 2 Enterprise Architecture**

This task will produce the enterprise architecture for the combat system.

Inputs: Enterprise requirements

Tools: CORE

Outputs: Enterprise architecture

- **Task 3 Value System Design**

This task will produce a value tree, which decomposes the architecture down to applicable functional levels. This task will identify metrics, such as performance measures.

Inputs: Enterprise requirements and architecture

Tools: CORE

Outputs: Metrics and threshold values

## **Modeling and Analysis Phase**

- **Task 1 Modeling and Simulation**

This task will produce models to simulate the architecture requirements and to validate the architecture developed in the previous phases. This task will also provide input to the cost analysis.

Inputs: Value system design, enterprise architecture and requirements

Tools: CORE, Arena, Microsoft Excel

Outputs: Simulation output and description

- **Task 2 Cost Analysis**

This task will explore life cycle costs associated with common ship C2 (combat) enterprise requirements across platforms.

Inputs: Historical cost data, enterprise architecture and requirements

Tools: Microsoft Excel, Visibility and Management of Operating and Support Costs (VAMOSC) database

Outputs: Cost analysis

## **SCHEDULE & DELIVERABLES**

### **Schedule**

The schedule developed for the ER&A project is shown in Figure 4. The period of performance is defined as September 2008 through June 2009. The schedule is driven by the milestones identified below:

- Approval of PMP
- Integrated Product Reviews (#1, #2, final brief out)
- Completion of the Systems Engineering Design Process phases

## **Deliverables**

The following deliverables have been identified for advisor and stakeholder concurrence:

- November 2008: PMP
- December 2008: IPR 1 Presentation, Report Draft Release #1 which will focus on:
  - Program Management Plan
  - Needs Analysis Overview
  - Stakeholder Analysis
  - Mission Thread Definition
  - Threat Assessment
  - Risk Management Update
  - The Way Forward
- March 2009: IPR 2 Presentation, Report Draft Release #2 which will focus on:
  - Updates from IPR #1
  - Functional Analysis Overview
  - Requirements Definition
  - Functional Architecture Status
  - Value System Design
  - Risk Management Update
  - The Way Forward
- June 2009: Final Presentation; Final Report
  - Updates from IPR #2
  - Final Functional Analysis
  - Modeling and Simulation Overview
  - Modeling and Simulation Results
  - Cost Analysis
  - Risk Management Update

Each IPR will include three basic sections. A progress update will focus on the work and products that been completed. A risk management update will focus on the risks identified and mitigation strategies developed for medium to high risks. The third section of each IPR will

include a way forward, in which the team schedule for the future will be reviewed. In these IPRs the team will elicit feedback from the stakeholders and advisors. Any comments provided will be addressed prior to the final presentation.

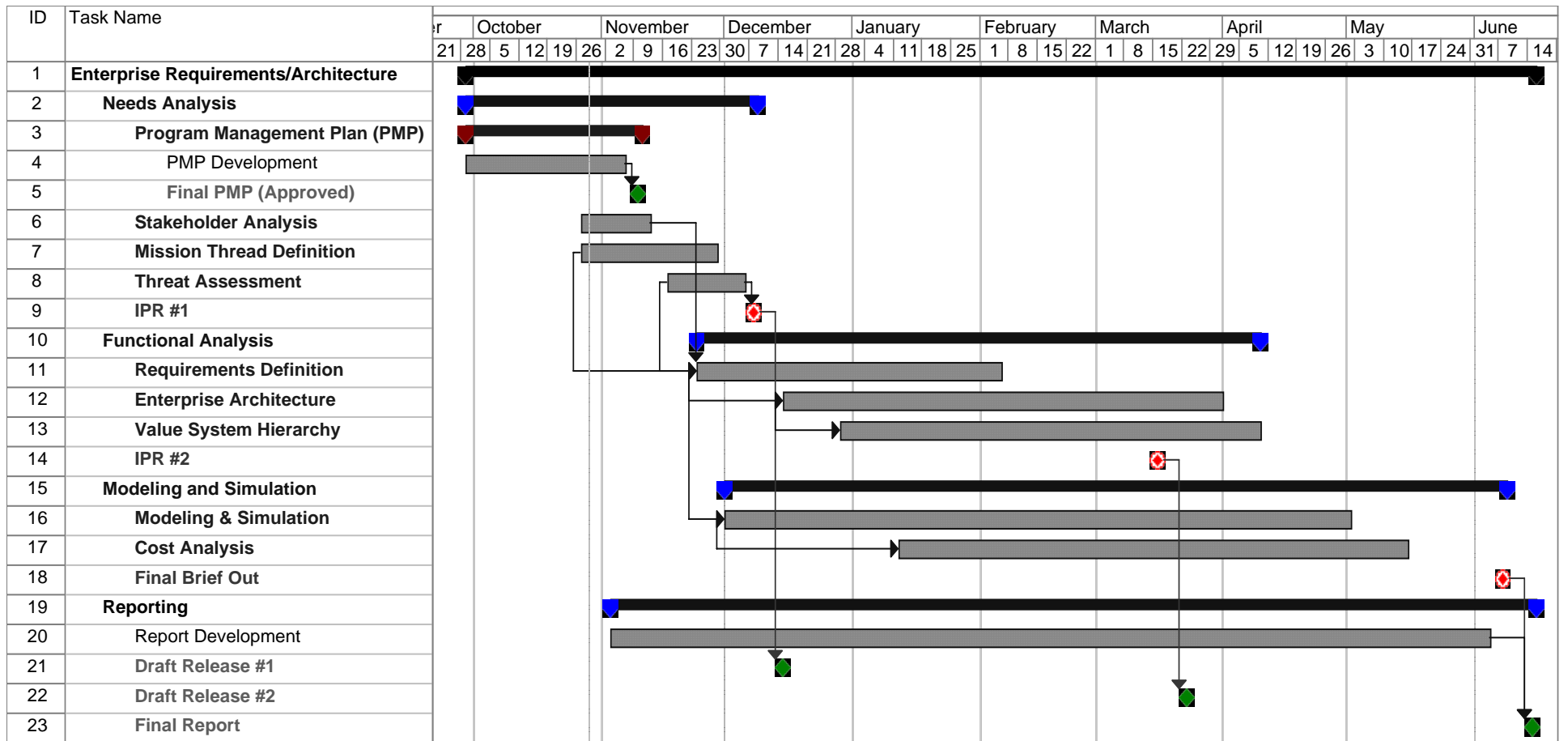


Figure 4: Schedule

## **PMP: References**

Department of Defense (DoD), *Risk Management Guide for DOD Acquisition*, Sixth Edition Version 1.0, Department of Defense, August 2006

Department of Defense Command and Control Research Program (DoDCCRP), *Representative Measures of a Single Integrated Air Picture*, Department of Defense, downloaded on 2 October 2008 from <http://www.dodccrp.org/files/SIAP.pdf>

Defense Acquisition University (DAU), *System Engineering Fundamentals*, Fort Belvoir, Virginia, Defense Acquisition University Press, January 2001

Naval Post Graduate School (NPS), *SE Writing Standards*, Monterey, California, Naval Post Graduate School, October 2006, downloaded on 29 September 2008 from <https://nps.blackboard.com>



## **PMP: Appendix A: Acronym List**

<b>Acronym</b>	<b>Term</b>
AV	All View
C2	Command and Control
C4I	Command, Control, Communications, Computers, Intelligence
CG	Guided Missile Cruiser
COP	Common Operational Picture
CTP	Common Tactical Picture
DCO	Defense Connect Online
DDG	Guided Missile Destroyer
DoDCCRP	Department of Defense Command and Control Research Program
DoDAF	Department of Defense Architecture Framework
ER&A	Enterprise Requirements and Architecture
EFFBD	Extended Functional Flow Block Diagram
FFG	Guided Missile Frigate
IPR	Integrated Product Review
IPT	Integrated Product Team
IWS	Integrated Warfare Systems
M&S	Modeling & Simulation
MIO	Maritime Interception Operations
MSSE	Masters of Science in Systems Engineering
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
OV	Operational View
PEO	Program Executive Office
PMP	Project Management Plan
POA&M	Plan of Action & Milestones
SE	Systems Engineering
SEDP	Systems Engineering Design Process
SI	System Integration
SUW	Surface Warfare
TA	Technical Assistant
VAMOSC	Visibility and Management of Operating and Support Cost

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## **APPENDIX B: STAKEHOLDER INTERVIEW QUESTIONS**

1. What are the future trends in Surface Warfare and Maritime Interdiction Operations that will drive ship combat system requirements?

a. Technical  
e.g. OA, SOA

b. Operational  
e.g. Distributed operations

2. What are the major current and emerging surface threats to U.S. Navy platforms that the ship combat system must address?

e.g. Cyber attacks, piracy, semi-submersible or other low-observable surface vessels, FAC/swarm attacks, suicide attack by unmarked (civilian) vessels

3. Limited to the Surface Warfare and Maritime Interception Operations, what major requirements can you identify for the ship's combat system?

a. Relative to functionality the ship combat system must support?

b. Relative to the performance or operational availability of the system?

c. Relative to specific requirements for system (ship and coalition) redundancy?

d. Relative to the current & future interfaces the ship combat system must support?

e. Relative to the operational environment that the ship combat system must operate in?

4. What are the performance and/or RMA criteria that define the "goodness" of the ship combat system?

5. What performance aspects of the ship combat systems are most important? Which are least important?

6. Are there any constraints on the combat system that we need to include in our requirements analysis?

7. Are there any cost or schedule constraints that we need to be aware of?

e.g. Weapon system must be ready for certain test events X months prior to full ship test events.

8. How does the trend toward net-centricity & reliance upon coordinated tracks, cooperative fires, etc. impact combat system command and control functionality and performance?

9. Does the trend toward net-centricity & reliance upon coordinated tracks, cooperative fires, etc. drive navigation accuracy or track measurement report precision, gridlock precision, track update rates, or other performance metrics?
10. What do you expect as the final product of this effort? Do you expect a section of a formal requirements document or a product that would be expanded by a follow-on effort?
11. Do you have any additional comments or recommendations? Do you know of any other stakeholders we could speak with from the resource sponsor (OPNAV) or fleet (CFFC)?

## **APPENDIX C: C2 REQUIREMENTS, VSD & ARCHITECTURE MATRIX**

In Table 11 each requirement is listed in the “Requirements” column and is tracked by number in a hierarchical arrangement in which higher level requirements are decomposed into multiple lower level requirements, as indicated by the number of decimal points in the requirement number. (Requirement 1.2 decomposed into 1.2.1, 1.2.2, etc.) The “Rationale” column contains the source information for that requirement, and may be attributed to a Joint or Navy publication, a stakeholder, the mission threads, or another doctrinal source. In the case where the rationale refers to an NTA, definition can be found in the Navy Tactical Task List. Requirements that do not reference an external source were derived as necessary to ‘fill in’ the architecture when required. The “Type” column indicates whether a requirement is a functional or performance requirement, or a constraint. Functional requirements describe what the system must be able to do. Performance requirements describe how well the system must perform. Constraint requirements describe other operational or design limitations with which the system must comply. The “Value System Design” column further describes the requirement in terms of the intended objective and Performance Measures. The “Architecture Function” column contains the architecture function to which the requirement has been allocated. Only the lowest leaf levels in the requirements hierarchy have been allocated to functions. A “leaf” is the lowest decomposition of a requirement in the hierarchy. The leaf level requirements and associated functions support the higher level, or parent, requirement.

**Table 11: Complete C2 Requirements and VSD**

This table contains a complete listing of all System Requirements and the Value System Design.

Requirement	Rationale	Type	Value System Design	Architecture Function
1 Command and Control The system shall support Command and Control activities.		Functional		
1.1 Conduct Maritime Interception The C2 system shall support maritime interception operations.	NTA 1.4.6	Functional	Obj: Assess if visit and boarding were successful.  PERFORMANCE MEASURE: Ability of C2 system to support visit and board contact.  Goal: 99% of all MIO Missions conducted successfully	
1.1.1 Conduct Visit The C2 system shall provide the capability for ship personnel to request a vessel to heave to, for purposes of conducting a visit.	NTA 1.4.6.1	Functional	Obj: Assess if boarding party and C2 can successfully inspect and examine a vessel.  PERFORMANCE MEASURE: Ability of C2 to facilitate conducting a visit on a vessel.  Goal: 99% of all MIO visits successful	

Requirement	Rationale	Type	Value System Design	Architecture Function
1.1.1.1 Query The system shall support the querying of vessels and the transmissions of notifications to conduct VBSS operations.		Functional	Obj: Assess if ship personnel can successfully query a vessel.  PERFORMANCE MEASURE: Ability of C2 to facilitate query of a vessel.  Goal: 99% of all MIO queries successful	3.4 Query Ship
1.1.1.2 Request to Board The C2 system shall provide the capability for ship personnel to request a vessel to heave to, for purposes of conducting a visit.	NTA 1.4.6.1	Functional	Obj: Assess if the request to board is communicated.  PERFORMANCE MEASURE: Ability of C2 to effectively communicate a request to board transmission.  Goal: 99% of all MIO transmissions and receipt of all boarding message are successful.	3.5 Issue Boarding Order
1.1.2 Conduct Search The C2 system shall support vessel searches.	NTA 1.4.6.2	Functional	Obj: Assess if C2 effectively starts a search plan.  PERFORMANCE MEASURE: Ability of C2 system to find contact and evaluate the compliance of the vessel under evaluation.  Goal: Probability of detection of a contact during sensor scans > 99%	3.5 Issue Boarding Order

Requirement	Rationale	Type	Value System Design	Architecture Function
1.1.3 Conduct Seizure The C2 system shall support the capability to identify any violation of resolutions or sanctions.	NTA 1.4.6.3	Functional	Obj: Assess if C2 system effectively supports personnel in seizure of a vessel.  PERFORMANCE MEASURE: Capability of C2 system to identify vessels in violation of resolutions and/or sanctions.  Goal: Probability of correct ID of a contact > 99%	
1.1.3.1 Take Possession of Vessel Upon identification of a resolution or sanction violation, the C2 system shall support the action of taking legal possession of the vessel.	NTA 1.4.6.3	Functional	Obj: Assess if C2 correctly IDs that vessel is in possession  PERFORMANCE MEASURE: Capability of C2 to correctly Identify vessels in possession  Goal: Probability of correct ID of a vessel in violation >99%	3.5 Issue Boarding Order
1.1.3.2 Take Possession of Contraband Upon identification of a resolution or sanction violation, the C2 system shall support the action of taking legal possession of the contraband, to include goods and people.	NTA 1.4.6.3	Functional	Obj: Assess if C2 correctly IDs vessels contents  PERFORMANCE MEASURE: Capability of C2 to correctly Identify a vessel's contents  Goal: Probability of correct ID of contents of a suspected vessel >99%	3.5 Issue Boarding Order



Requirement	Rationale	Type	Value System Design	Architecture Function
1.1.4 Maritime Interception Operations (MIO) Reporting The C2 system shall support the automated reporting of query and boarding status and Situation Reports (SITREP).	USN/USCG 2003	Functional	Obj: Assess if C2 reports information regarding queries and boarding activity  PERFORMANCE MEASURE: Capability of C2 to report out information regarding MIO activities.  Goal: Probability of correctly reporting of query/boarding status >99%	
1.1.4.1 Maintain Status The C2 system shall maintain a query and boarding status for each MIO action.	Stakeholder Analysis	Functional	Obj: Asses C2 functionality in maintaining status on all boarding and query activities  PERFORMANCE MEASURE: Measure C2 capability in maintaining a database of all boarding and query activities  Goal: C2 shall keep an active link on status of boarding party > 99%	3.4 Query Ship 3.5 Issue Boarding Order
1.1.4.2 Provide Reports The C2 system shall provide surface situation reports.	Stakeholder Analysis	Functional	Obj: Assess C2 ability in producing reports  PERFORMANCE MEASURE: Measure C2 effectiveness in producing reports  Goal: Meantime for C2 to provide reports to CO < 5 mins.	4 Report Status

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.1.5 Classify and Identify Surface Contacts</p> <p>The C2 system shall utilize stored intelligence data to classify and identify surface contacts.</p>	USN/USCG 2003	Functional	<p>Obj: Determine C2 classification completeness and accuracy</p> <p>PERFORMANCE MEASURE: Ability to classify as friend, foe, suspect, or assumed friend based on database information</p> <p>Goal: Accuracy and completeness of surface contacts &gt;95%</p>	<p>2.3 Classify Tracks</p> <p>2.4 Identify Tracks</p>
<p>1.2 Collect Target Information</p> <p>The C2 system shall collect target information for detecting, identifying, locating, and classifying targets.</p>	NTA 2.2.1	Functional	<p>Obj: Determine C2 capability of sensors to identify an object under varied noise, weather, terrain conditions</p> <p>PERFORMANCE MEASURE: Ability of sensors to identify an object under varied noise, weather, terrain conditions</p> <p>Goal: Probability of detection and classification of a target &gt;99%</p>	

Requirement	Rationale	Type	Value System Design	Architecture Function
1.2.1 Receive Sensor Inputs The C2 system shall utilize radar, electro-optical/infrared (EO/IR), electronic surveillance (ES), identification friend-or-foe (IFF) and automatic identification system (AIS) data in the classification and identification of contacts.	Goddin, 2008; Haas & Neel, 2008	Functional	Obj: Assess C2 functionality in receiving data from sensors in detection, ID, and classification of contacts.  PERFORMANCE MEASURE: Ability of C2 to correctly and accurately detect, Identify, classify contacts from sensor data  Goal: Probability of correct detection, ID, and classification from all sensor systems >85%	
1.2.1.1 Sensor Data The track file shall include radar, EO/IR, ES, acoustic, IFF and AIS data.		Functional	(same as 1.2.1)	2.1 Store and Report Tracks
1.2.1.2 Correlate Sensor Data The C2 system shall correlate radar, EO/IR, ES, acoustic, IFF and AIS data into a single track file.		Functional	(same as 1.2.1)	2.5 Correlate/Decorrelate Tracks 2.6 Associate Bearings/Fixes to Tracks
1.2.2 Classify Surface Contacts The C2 system shall classify surface contacts.	NTA 2.2.1.3	Functional	Obj: Determine C2 ability to assess contact classification completeness and accuracy  PERFORMANCE MEASURE: Ability of C2 to accurately and completely classify all contacts.  Goal: Probability of correct classification and accuracy of surface contacts >99%	

Requirement	Rationale	Type	Value System Design	Architecture Function
1.2.2.1 Classification Types Classification types shall include: combatant, noncombatant military, merchant, fishing, pleasure.	NWP 3-20	Functional	Obj: Determine if C2 can appropriately classify vessels by type or category (combatant, non-combatant military, merchant, fishing, etc).  PERFORMANCE MEASURE: Ability of C2 to classify by type of vessel  Goal: Probability of correct classification of vessel type/category >99%	2.3 Classify Tracks
1.2.2.2 Sensor Inputs The C2 system shall use inputs from organic and national asset sensors to classify contacts.		Functional	Obj: Assess C2 functionality in using data from organic and national asset sensors to classify contacts.  PERFORMANCE MEASURE: Ability of C2 to effectively use inputs from organic and national asset sensors to classify contacts.  Goal: Probability of correct classification based on asset sensors >85%	2.3 Classify Tracks
1.2.2.3 Classification Completeness The C2 system shall assign a classification to TBD % of detected surface contacts.	NTA 2.2.1.3.M1	Performance		2.3 Classify Tracks

Requirement	Rationale	Type	Value System Design	Architecture Function
1.2.2.4 Classification Accuracy The C2 system shall assign a correct classification to TBD % of classified surface contacts.		Performance		2.3 Classify Tracks
1.2.2.5 Classification Timeliness The C2 system shall correctly classify TBD % of detected contacts within TBD minutes.	NTA 2.2.1.3.M3	Performance		2.3 Classify Tracks
1.2.3 Identify Contacts The C2 system shall identify contacts as friendly or hostile.	JP 1-02, NTA 2.2.1.4	Functional	Obj: Determine C2 ability to ID contacts  PERFORMANCE MEASURE: Ability of C2 to correctly and accurately ID contacts  Goal: Probability of correct and accurate ID of contacts during active scanning >99%	
1.2.3.1 Identification Completeness The C2 system shall assign an identity to TBD % of classified surface contacts.	NTA 2.2.1.4.M3	Performance		2.4 Identify Tracks
1.2.3.2 Identification Accuracy The C2 system shall assign the correct identity to TBD % of identified surface contacts.		Performance		2.4 Identify Tracks
1.2.3.3 Identification Timeliness The C2 system shall correctly identify TBD % of classified contacts as friendly or hostile within TBD minutes.	NTA 2.2.1.4.M1	Performance		2.4 Identify Tracks

Requirement	Rationale	Type	Value System Design	Architecture Function
1.2.3.4 Automated Identification The system shall use range ring, radar, EO/IR, ES, acoustic, IFF and AIS data to identify targets.	Haas & Neel 2008	Functional	Same as sensor requirements /PMs/Goals	
1.2.3.4.1 Kinematic Information The C2 system shall use kinetic information to identify targets.	Haas & Neel 2008	Functional	Same as sensor requirements /PMs/Goals	2.4 Identify Tracks
1.2.3.4.2 Muzzle Flash The C2 system shall use muzzle flashes to identify targets.	Haas & Neel 2008	Functional	Same as sensor requirements /PMs/Goals	2.4 Identify Tracks
1.2.4 Localize Contacts The C2 system shall localize the position of surface contacts.	NTA 2.2.1.5	Functional	Obj: Assess if C2 can create tracks from multiple sources of data and communication networks of detected contacts  PERFORMANCE MEASURE: Ability of C2 to create local and composite tracks of contacts detected  Goal: Probability of creating correct and accurate tracks of surface contacts >85%	
1.2.4.1 Track & Status Reporting The C2 system shall report track data for all surface contacts and own ship status data via Link-16 and GCCS-M.		Functional	Same as 1.2.4 objectives and performance measures	2.1 Store and Report Tracks

Requirement	Rationale	Type	Value System Design	Architecture Function
1.2.4.2 Sensor Netting and Distributed Weapons Control The C2 system shall be able to exchange contact data with other platforms to form local tracks.	Haas & Neel 2008	Functional	Same as 1.2.4 objectives and performance measures	
1.2.4.2.1 Engagement The C2 system shall be able to engage targets using contact data from other platforms.	Haas & Neel 2008	Functional	<p>Obj: Determine C2 ability to issue engagement orders from contact data.</p> <p>PERFORMANCE MEASURE: Capability of C2 to issue engagement orders from contact data</p> <p>Goal: Mean time in issuing engagement order &lt; 30 seconds</p>	2.2 Form Tracks

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.2.4.2.2 Sensor Netting</p> <p>The C2 system shall be able to send contact reports to, and receive contact reports from, other platforms, using contact data from other platforms to form tracks with own ship contact reports.</p>		Functional	<p>Obj: Assess C2 ability to participate in a sensor/net centricity environment</p> <p>PERFORMANCE MEASURE: Capability of C2 to send and receive contact reports. Capability of C2 to use contact data from other platforms to form tracks with own ship contact reports.</p> <p>Goals: Probability of successful transmission and receipt of contact reports &gt; 95% Probability of successful integration of other platform contact data &gt; 95%</p>	2.2 Form Tracks
<p>1.2.5 MIO Intelligence</p> <p>The C2 system shall utilize available intelligence data to classify and identify surface contacts</p>		Functional	<p>Obj: Determine C2 ability in utilizing available database intelligence to classify and ID contacts</p> <p>PERFORMANCE MEASURE: Ability of C2 to correctly and accurately classify and ID contacts</p> <p>Goal: Probability of correct and accurate classification and ID &gt;99%</p>	



<b>Requirement</b>	<b>Rationale</b>	<b>Type</b>	<b>Value System Design</b>	<b>Architecture Function</b>
<b>1.2.5.1 Automatic Identification System</b> The C2 system shall use commercial vessel intelligence data to support the classification and identification of surface contacts.	USCG 2008	Functional	Same as 1.2.5 objectives and Performance measures	2.4 Identify Tracks
<b>1.2.5.2 National Asset Intelligence</b> The C2 system shall receive, parse and store intelligence data from National Intelligence Assets, including National Maritime Intelligence Center (Merchant Ship Characteristics & Hidden Compartment Book) and Sealink Database of Vessels (ELINT parameters of known vessels).	USN/USCG 2003; MIO thread	Functional	Same as 1.2.5 objectives and Performance measures	2.4 Identify Tracks
<b>1.2.6 Link Planning</b> The system shall be able to receive, parse and apply the OPTASK LINK	derived	Functional		3.6.3 Develop Track Management Policy

Requirement	Rationale	Type	Value System Design	Architecture Function
1.3 Process Targets The C2 system shall process surface targets to employ response systems.	NTA 3.1	Functional	Obj: Assess C2 capability to correctly and accurately ID/classify contacts and make command and decision (C&D) in contact processing and action to contacts  PERFORMANCE MEASURE: Evaluate C2 ability to process ID and classification of contacts in making C&D actions.  Goal: Probability of correct action based on ID and classification >99.9%	
1.3.1 Pre-planned Responses (PPR) The C2 system shall be able to receive, parse and implement PPRs.	CNO 2007	Functional	Same as 1.3 objectives and Performance measures	3.6.1 Develop Engagement Guidance
1.3.2 Request Attack The C2 system shall be able to order an attack on a specific target or position.	NTA 3.1.1	Functional	Same as 1.3 objectives and Performance measures	
1.3.2.1 Request Timeliness The C2 system shall submit TBD% of all attack requests within TBD minutes.	NTA 3.1.1.M2	Performance	Obj: To submit attack requests in a timely manner.  PERFORMANCE MEASURE: Timeliness of attack requests  Goal: The C2 system shall submit TBD% of all attack requests within TBD minutes.	3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options 3.3 Issue Engagement Order

<b>Requirement</b>	<b>Rationale</b>	<b>Type</b>	<b>Value System Design</b>	<b>Architecture Function</b>
1.3.3 Select Surface Target to Attack The C2 system shall select the surface target to attack.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	
1.3.3.1 Define Target Selection Criteria The C2 system shall allow for definition of target selection criteria for attack.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	3.1.1 Identify Threats 3.1.2 Prioritize Threats 3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options
1.3.3.2 Weapon Intercept Points The C2 system shall determine weapon intercept points.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	
1.3.3.2.1 Correlate Target Reports The C2 system shall correlate target reports into a track list and maintain the target list.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	2.5 Correlate/Decorrelate Tracks
1.3.3.2.2 Update Intercept Points The C2 system shall update weapon intercept points.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	3.1.3 Identify Actions Required for Each Threat 3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options
1.3.3.2.3 Duplicate Tracks The C2 system shall avoid duplicate track files for single objects.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	2.5 Correlate/Decorrelate Tracks

Requirement	Rationale	Type	Value System Design	Architecture Function
1.3.3.3 Examine Target The C2 system shall examine each target to determine if and by what time to issue an attack order.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	2.4 Identify Tracks 2.5 Correlate/Decorrelate Tracks 2.6 Associate Bearings/Fixes to Tracks 3.1.1 Identify Threats 3.1.2 Prioritize Threats 3.1.3 Identify Actions Required for Each Threat
1.3.3.3.1 Target Evaluation Percentage The C2 system shall evaluate TBD% of all targets identified for attack.	NTA 3.1.2.M1	Performance		3.1.1 Identify Threats 3.1.2 Prioritize Threats 3.1.3 Identify Actions Required for Each Threat
1.3.3.3.2 Evaluation Timeliness The C2 system shall complete target selection within TBD minutes after the contact has been localized or identified (whichever is greater).	NTA 3.1.2.M3	Performance		3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options
1.3.3.4 Maintain Target List The C2 system shall maintain the target list.		Functional	Same as 1.3 objectives and Performance measures	2.7 Manage Track Numbers
1.3.3.5 Track Data Comparison The C2 system shall allow for comparison of target track data to selection criteria.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	2.5 Correlate/Decorrelate Tracks 3.1.2 Prioritize Threats 3.1.3 Identify Actions Required for Each Threat
1.3.3.6 Warning Orders The C2 system shall be able to issue warning orders to targets selected for attack.	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	3.1.3 Identify Actions Required for Each Threat

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.3.4 Select Platform(s) and System(s) for Attack</p> <p>The C2 system shall determine best weapon system, based on availability, intercept time, intercept point, and probability of negation, to employ against a particular target.</p>	NTA 3.1.3	Functional	<p>Obj: To determine capability of C2 to select best weapon system for target</p> <p>PERFORMANCE MEASURE: Mean time for selected weapon system to engage target. Accuracy of target impact.</p> <p>Goals: Missile: Time &lt; 5 minutes , Accuracy of engagement &gt; 99% Small Boat: Time less than X minutes, Accuracy &gt; 99% Ship: Time less than 5 minutes, Accuracy &gt;99%</p>	
<p>1.3.4.1 Process Weapon System Status</p> <p>The C2 system shall process status information from the engaging weapon system.</p>	NTA 3.1.3	Functional	<p>Obj: To determine capability of C2 to process weapon status information.</p> <p>PERFORMANCE MEASURE: 1) Probability of accurately determining weapon system availability and ready status  2) Mean time to determine weapon system availability and ready status</p> <p>Goal: Accuracy &gt; 99% Mean Time &lt; 5 minutes</p>	3.2.1 Estimate Engagement Effectiveness

Requirement	Rationale	Type	Value System Design	Architecture Function
1.3.4.2 Weapon-Target Pairing The C2 system shall assign all high priority targets to at least one engagement system.	NTA 3.1.3.M1	Performance		3.2.3 Compile Weapon Target Pairing Options
1.3.4.3 Pairing Timeliness The C2 system shall complete weapon-target pairing within TBD seconds after a target has been assigned for attack.	NTA 3.1.3.M2	Performance		3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options
1.3.4.4 Engagement Coordination The system shall be able to support coordination of engagements with other operational nodes and friendly forces.		Functional	Obj: To determine capability of C2 to coordinate weapon engagements with other platform C2 systems.  PERFORMANCE MEASURE: Percent of surrounding C2 platforms notified of weapon engagement plans.  Goal: Notified C2 of pending, prior, and future engagements > X%	1.3 Display Engagement/VBSS Status 1.5 Display Command Data 3.2.1 Estimate Engagement Effectiveness 3.2.2 Identify Engagement Conflicts 3.2.3 Compile Weapon Target Pairing Options 3.6.1 Develop Engagement Guidance 3.6.2 Develop Sensor Plans

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.3.4.5 Control of Non-Kinetic Effectors</p> <p>The C2 system shall be able to employ non-kinetic effectors, including RF weapons, prop-fouling devices and ES systems.</p>	Stockbauer 2008	Functional	<p>Obj: To determine capability of C2 to employ non-kinetic effectors.</p> <p>PERFORMANCE MEASURE: Percent of non-kinetic effectors available for use.</p> <p>Goal: Available non-kinetic effectors for operational use &gt; 99%</p>	
<p>1.3.4.5.1 Non-Kinetic Weapons Assignment</p> <p>The C2 system shall be able to estimate the effectiveness of non-kinetic effectors against all tracks and present all kinetic and non-kinetic effect or options to the operator.</p>		Functional	<p>Obj: To determine capability of C2 to select best non-kinetic effect or for target</p> <p>PERFORMANCE MEASURE: Mean time for selected non-kinetic effect to impact target.</p> <p>Goal: Time &lt; 15 minutes</p>	<p>3.2.1 Estimate Engagement Effectiveness</p> <p>3.2.2 Identify Engagement Conflicts</p>
<p>1.3.4.5.2 Non-Kinetic Weapons Control</p> <p>The C2 system shall be able to control non-kinetic weapons.</p>		Functional	<p>Obj: To determine the capability of C2 in utilizing non-kinetic WCS.</p>	3.3 Issue Engagement Order
<p>1.3.4.6 Use Rules of Engagement</p> <p>The C2 system shall allow for input of rules of engagement and armed laws of conflict and their use in the target selection for attack decision.</p>	NTA 3.1.2	Functional	Same as 1.3 objectives and Performance measures	<p>3.1.1 Identify Threats</p> <p>3.1.2 Prioritize Threats</p> <p>3.1.3 Identify Actions Required for Each Threat</p> <p>3.3 Issue Engagement Order</p>

Requirement	Rationale	Type	Value System Design	Architecture Function
1.3.5 Develop Order to Fire The C2 system shall send a weapon fire order instruction to the selected platform and weapon system with target track parameters, required intercept parameters and weapon type.	NTA 3.1.4	Functional	Obj: To determine capability of C2 to develop 'order to fire'  PERFORMANCE MEASURE: Completeness of Firing Order Instruction.  Goal: Completeness of firing order during operation > 99%	
1.3.5.1 Fire Order Timeliness The C2 system shall develop and issue an order to fire within TBD seconds after the completion of weapon-target pairing.	NTA 3.1.4.M1	Performance		3.3 Issue Engagement Order
1.3.5.2 Correct Fire Orders The C2 system shall correctly prepare all fire orders.	NTA 3.1.4.M2	Performance		3.3 Issue Engagement Order
1.3.5.3 Correct Engagement System The C2 system shall issue TBD% of fire orders to the correct engagement system.	NTA 3.1.4.2.M3	Performance		3.3 Issue Engagement Order



Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.3.6 Conduct Tactical Combat Assessment</p> <p>The C2 system shall assess the success of the engagement.</p>	NTA 3.1.5	Functional	<p>Obj: To determine capability of C2 to complete battle damage assessment, complete munitions effect assessment, and provide re-attack recommendations (if necessary).</p> <p>PERFORMANCE MEASURE:</p> <p>Accuracy of battle damage assessment.</p> <p>Accuracy of munitions effect assessment.</p> <p>Accuracy of Re-attack recommendations.</p> <p>Goal: Battle Damage Assessment Accuracy &gt; 99%</p> <p>Munitions Effect Assessment Accuracy &gt; 99%</p> <p>Re-attack recommendation accuracy &gt; 99%</p>	
<p>1.3.6.1 Attack Assessment Availability</p> <p>The C2 system shall provide combat assessment for TBD% of all engaged targets.</p>	NTA 3.1.5.M1	Performance		3.7 Assess Engagement

Requirement	Rationale	Type	Value System Design	Architecture Function
1.3.6.2 Attack Assessment Timeliness The C2 system shall complete assessment of attacks within TBD minutes.	NTA 3.1.5.M3	Performance		3.7 Assess Engagement
1.3.6.3 COA Assessment The C2 system shall assess the course of action upon completion of the engagement.		Functional		3.1.2 Prioritize Threats 3.1.3 Identify Actions Required for Each Threat
1.4 Information Exchange The C2 system shall have the capability to exchange information with shipboard and national assets.	NTA 5.1.1, SUW & MIO Threads	Functional	<p>Obj: Assess C2 capability in exchanging information with allied participants</p> <p>PERFORMANCE MEASURE: Evaluate C2 capability in exchanging data to necessary participants</p> <p>Percent of shipboard assets with the capability to exchange information with C2.</p> <p>Percent of national assets with the capability to exchange information with C2.</p> <p>Goal: Shipboard Communication &gt; 99%</p> <p>National Asset Communication &gt; 99%</p>	

Requirement	Rationale	Type	Value System Design	Architecture Function
1.4.1 Data Format The C2 System data format shall be compatible with TBD information systems as defined in TBD Interface requirements documents.		Functional	<p>Obj: To determine if C2 data is compatible with TBD information system.</p> <p>PERFORMANCE MEASURE: Percent of data format compatibility.</p> <p>Goal: Data Compatibility among systems &gt; 85%</p>	<p>2.1 Store and Report Tracks</p> <p>2.2 Form Tracks</p> <p>3.1.1 Identify Threats</p> <p>3.6 Develop Execution Guidance</p> <p>4 Report Status</p>

Requirement	Rationale	Type	Value System Design	Architecture Function
1.4.2 Data Exchange The C2 system shall support obtaining, relaying, and distributing data and information with service, joint, interagency, intra-agency, and coalition forces.	NTA 5.1.1	Functional	<p>Obj: To determine capability of C2 to exchange information with services, joint interagency, intra-agency, and coalition forces.</p> <p>PERFORMANCE MEASURE: Percent of data successfully relayed to services, joint interagency, intra-agency, and coalition forces.</p> <p>Percent of data successfully obtained from services, joint interagency, intra-agency, and coalition forces.</p> <p>Percent of data successfully distributed to services, joint interagency, intra-agency, and coalition forces</p> <p>Goal: Successful relay &gt; 99%</p> <p>Successful data acquisition &gt; 99%</p> <p>Successful data distribution &gt; 99%</p>	<p>2.1 Store and Report Tracks</p> <p>2.2 Form Tracks</p> <p>3.1.1 Identify Threats</p> <p>3.6 Develop Execution Guidance</p> <p>4 Report Status</p>
1.4.2.1 Data Exchange Information Information shall include mission, courses of action, tasking orders, operational plans and orders, intelligence, environmental conditions, friendly unit status and location, relaying I&W information.		Functional	Same as 1.4 objectives and Performance measures	<p>1.2 Display Track Data</p> <p>1.3 Display Engagement/VBSS Status</p> <p>1.4 Display Sensor Status</p> <p>1.5 Display Command Data</p>

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.4.3 Information Types</p> <p>The C2 system shall utilize joint communication links to distribute data to include mission, intelligence, status, and other reports, e.g. courses of action, tasking orders, operational plans and orders, environmental conditions, friendly unit status and location, I&amp;W information.</p>	NTA 5.1.1	Functional	<p>Obj: To determine capability of C2 to distribute data via joint communication links.</p> <p>PERFORMANCE MEASURE: Percent of joint communication links usable by the C2 system.</p> <p>Goal: Usability of Joint Communication Links &gt; 85%</p>	<p>2.1 Store and Report Tracks</p> <p>2.2 Form Tracks</p> <p>3.1.1 Identify Threats</p> <p>3.6 Develop Execution Guidance</p> <p>4 Report Status</p>
<p>1.5 Maintain Information and Naval Force Status</p> <p>The C2 system shall maintain data and information for decision making and maintaining a tactical picture.</p>	NTA 5.1.3	Functional	<p>Obj: To determine capability of C2 to maintain information and Naval Force Status</p> <p>PERFORMANCE MEASURE: Percent of data stored.</p> <p>Accuracy of Naval Force status</p> <p>Goal: Data storage &gt; 99%</p> <p>Accuracy of Naval Force Status &gt; 85%</p>	
<p>1.5.1 Suitable Display Format</p> <p>Decisions delayed because the C2 data is not presented to the decision maker in a suitable format shall not exceed 0.01%(threshold), 0.001% (objective)</p>	NTA 5.1.3.M3 CPD for GCCS-M v4.	Performance		<p>1.1 Provide Tactical Display Configuration Options</p> <p>1.3 Display Engagement/VBSS Status</p> <p>1.4 Display Sensor Status</p> <p>1.5 Display Command Data</p>

Requirement	Rationale	Type	Value System Design	Architecture Function
1.5.2 System Updates (U) The C2 system track file and displays shall be updated within 20 seconds of receiving updated data	NTA 5.1.3M1	Performance		1.2 Display Track Data 2.2 Form Tracks
1.5.3 Maintain and Display Tactical Picture The C2 system shall maintain and display a common tactical picture.	NTA 5.1.3.1	Functional	Obj: Assess C2 capability to maintain and display a tactical picture.  PERFORMANCE MEASURE: Evaluate C2 capability in maintaining a common tactical picture with all participants.  Goal: Meantime in C2 exchange of messages < 30 seconds	
1.5.3.1 Tactical Displays Operator consoles and displays showing tactical picture data shall utilize standard symbology.		Functional	Obj: Assess C2 capability in displaying battle space picture to operators  PERFORMANCE MEASURE: Evaluate C2 functionality in displaying information on the battle space to operators  Goal: Meantime in C2 exchange of messages < 30 seconds	1.3 Display Engagement/VBSS Status 1.4 Display Sensor Status 1.5 Display Command Data
1.5.3.2 Track Ambiguity The number of unresolved track ambiguities shall not exceed TBD per 24 hour period.	NTA 5.1.3.1.M1	Performance		2.5 Correlate/Decorrelate Tracks

<b>Requirement</b>	<b>Rationale</b>	<b>Type</b>	<b>Value System Design</b>	<b>Architecture Function</b>
1.5.3.3 Dual Tracks The percentage of dual tracks shall never exceed TBD% of all tracks displayed.	NTA 5.1.3.1.M2	Performance		2.5 Correlate/Decorrelate Tracks
1.5.3.4 Track Number Consistency The number of non-constant track numbers shall not exceed TBD per 24 hour period.	NTA 5.1.3.1.M3	Performance		2.7 Manage Track Numbers
1.5.3.5 Tactical Picture The C2 system shall meet the following performance requirements.	Stockbauer 2008	Performance		
1.5.3.5.1 Ambiguous Tracks The C2 system shall hold only a single track for each surface object for at least TBD percent of all surface contacts.	SIAP	Performance		2.5 Correlate/Decorrelate Tracks
1.5.3.5.2 Continuity The C2 system shall have fewer than TBD track number changes per surface contact during tracks life.	SIAP	Performance		2.7 Manage Track Numbers
1.5.3.5.3 Track Consistency The C2 system shall maintain a consistent track number, identity and kinematic data with Link-16 tracks for TBD percent of tracks.	SIAP	Performance		2.5 Correlate/Decorrelate Tracks 2.7 Manage Track Numbers

Requirement	Rationale	Type	Value System Design	Architecture Function
1.5.4 Maintain and Display Force Command and Coordination Status Operator consoles and tactical displays shall permit display of detailed data of own-force units, including unit ID, task organization and mission assignment.	NTA 5.1.3.2	Functional	<p>Obj: Assess C2 capability to maintain and display a tactical picture.</p> <p>PERFORMANCE MEASURE: Evaluate C2 capability in maintaining a common tactical picture with all participants.</p> <p>Goal: Meantime in C2 exchange of messages &lt; 30 seconds</p>	1.5 Display Command Data
1.5.5 Maintain and Display Unit Readiness Operator consoles and tactical displays shall permit display of detailed data of own-force units, including unit readiness, mission capability, weapon status, and fuel state.	NTA 5.1.3.3	Functional	<p>Obj: Assess C2 capability to maintain and display a tactical picture.</p> <p>PERFORMANCE MEASURE: Evaluate C2 capability in maintaining a common tactical picture with all participants.</p> <p>Goal: Meantime in C2 exchange of messages &lt; 30 seconds</p>	1.4 Display Sensor Status



Requirement	Rationale	Type	Value System Design	Architecture Function
1.6 Analyze and Assess The C2 system shall provide the commander with tactical situational awareness data; friendly force ID, task organization, task assignment, and readiness data; automated access to reference threat and intelligence data, decision aids and optask reference information suitable for effective command and control of assigned units.	NTA 5.2.1	Functional	Obj: Determine if C2 effectively communicates and transfers data and situational awareness to participants and commanders  PERFORMANCE MEASURE: Evaluate C2 effectiveness in communicated and displayed information regarding the situation, contacts, assets, and threats to participants and commanders.  Goal: Meantime in C2 exchange of messages < 30 seconds	
1.6.1 Tailor-able Display The system shall provide the ability for the user to tailor the display.		Functional		1.1 Provide Tactical Display Configuration Options
1.6.2 Situational Awareness TDAs The C2 system shall display situational awareness information to decision makers using tactical decision aids (TDAs).		Functional	Obj: Evaluate C2 capability in maintaining a common tactical picture with all participants.  PERFORMANCE MEASURE: Evaluate C2 capability in maintaining a common tactical picture with all participants.  Goal: Meantime in C2 exchange of messages < 30 seconds	1.3 Display Engagement/VBSS Status 1.4 Display Sensor Status 1.5 Display Command Data

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.6.3 Apply Rules of Engagement (ROE)</p> <p>The C2 system shall apply rules of engagement (ROE) to all developed plans and recommendations.</p>	NTA 5.2.1.3; SUW and MIO threads	Functional	<p>Obj: Assess C2 capability in effectively applying ROE</p> <p>PERFORMANCE MEASURE: Evaluated C2 effectiveness in applying ROE.</p> <p>Goal: Meantime in C2 exchange of engagement messages &lt; 30 seconds</p>	3.6.1 Develop Engagement Guidance
<p>1.6.4 Develop Courses of Action (COA)</p> <p>The C2 system shall develop courses of action (COAs).</p>	NTA 5.3.3, SUW & MIO threads	Functional	<p>Obj: Assess C2 capability in COAs in response to mission needs, environment, and contacts.</p> <p>PERFORMANCE MEASURE: Evaluate C2 response to mission needs, environment, and contacts via C2 COAs.</p> <p>Goal: Meantime for C2 to develop a COA &lt; 5 mins.</p>	
<p>1.6.4.1 COA Recommendations</p> <p>The C2 system shall recommend a minimum of TBD COAs per tactical action.</p>	NTA 5.3.3.M3	Performance		3.1.3 Identify Actions Required for Each Threat

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.6.4.2 COA Recommendation Ranking</p> <p>The C2 TDAs shall permit ranking of COA recommendations in order of assessed probability of success, confidence level, or other relevant performance measure.</p>		Functional	<p>Obj: Assess C2 capability in COAs in response to mission needs, environment, and contacts.</p> <p>PERFORMANCE MEASURE: Evaluate C2 response to mission needs, environment, and contacts via C2 COAs.</p> <p>Goal: Meantime for C2 to develop a COA &lt; 5 mins.</p>	3.2.3 Compile Weapon Target Pairing Options
<p>1.6.4.3 COA TDAs</p> <p>The C2 system shall display recommended COAs to decision makers using tactical decision aids (TDAs).</p>		Functional	<p>Obj: Assess C2 capability in COAs in response to mission needs, environment, and contacts.</p> <p>PERFORMANCE MEASURE: Evaluate C2 response to mission needs, environment, and contacts via C2 COAs.</p> <p>Goal: Meantime for C2 to develop a COA &lt; 5 mins.</p>	

Requirement	Rationale	Type	Value System Design	Architecture Function
1.7 Develop Search Plan The C2 system shall develop surface search plans.	SUW & MIO threads, NTA 5.3.3	Functional	<p>Obj: Determine C2 ability to develop a search plan in a dynamic environment</p> <p>PERFORMANCE MEASURE: Evaluate the ability of C2 to develop search plan to dynamic environments</p> <p>Goal: Meantime for C2 to develop a search plan &lt; 5 mins.</p>	
1.7.1 Types of Search Plans The C2 system shall be capable of developing area and directed search plans.	NWP 3-20	Functional	<p>Obj: Determine C2 ability to develop a search plan in a dynamic environment</p> <p>PERFORMANCE MEASURE: Evaluate the ability of C2 to develop search plan to dynamic environments</p> <p>Goal: Meantime C2 takes to initiate a search plan &lt; 10 seconds</p>	

Requirement	Rationale	Type	Value System Design	Architecture Function
<p>1.7.1.1 Search Plan Factors The C2 system shall have the capability to process the following information when developing search plans:</p> <ol style="list-style-type: none"> <li>1. Prior surveillance (leverage COP/CTP information)</li> <li>2. Historical operating pattern</li> <li>3. Platform endurance and range</li> <li>4. Weapons and sensor capabilities</li> <li>5. Size of the area and threat axis</li> <li>6. Search priorities</li> <li>7. Environmental factors</li> <li>8. Shipping density.</li> </ol>	NWP 3-20	Functional	<p>Obj: Determine C2 ability to develop a search plan in a dynamic environment</p> <p>PERFORMANCE MEASURE: Evaluate the ability of C2 to develop search plan to dynamic environments</p> <p>Goal: Meantime C2 takes to initiate a search plan &lt; X seconds</p>	3.6.2 Develop Sensor Plans
<p>1.7.2 Control Sensors The C2 system shall be able to direct sensors according to the approved search plan.</p>	SUW & MIO threads	Functional	<p>Obj: Determine C2 capability in directing sensor systems in an approved search plan</p> <p>PERFORMANCE MEASURE: Evaluate C2 ability in directing sensor systems</p> <p>Goal: Meantime C2 takes in sending a message to direct sensors &lt; 10 seconds</p>	3.6.2 Develop Sensor Plans
<p>1.7.3 Plan Suitability 100% of search plans developed by the C2 system shall be achievable.</p>	NTA 5.3.3.M1	Performance		3.6.2 Develop Sensor Plans
<p>1.7.4 Plan Timeliness The C2 system shall develop a search plan within 30 minutes.</p>	NTA 5.3.3.M2	Performance		3.6.2 Develop Sensor Plans

Requirement	Rationale	Type	Value System Design	Architecture Function
1.7.5 Alternative Plans The C2 system shall develop TBD# of alternative search plans.	NTA 5.3.3.M3	Performance		3.6.2 Develop Sensor Plans
1.8 Constraint Requirements		Constraint		
1.8.1 Lifecycle Impacts The C2 system shall satisfy the following life cycle requirements.	Stockbauer 2008	Constraint		
1.8.1.1 CRUDES Manning The C2 system shall not increase the manning requirements on any Navy ships.	Stockbauer 2008	Constraint	<p>The C2 system shall not increase the manning requirements on any Navy surface combatants.</p> <p>Obj: To maintain or decrease current manning levels for C2 system operation</p> <p>PERFORMANCE MEASURE: Manning levels required for operation</p>	
1.8.1.2 Training Costs The C2 system shall not increase the cost to train the operators of the C2 system.	Stockbauer 2008	Constraint	The C2 system shall not increase the cost to train the operators of the C2 system.	
1.8.1.3 Support Costs The C2 system shall not increase the cost to support the C2 system post-installation.	Stockbauer 2008	Constraint	The C2 system shall not increase the cost to support the C2 system post-installation.	
1.8.1.4 Operational Availability The C2 system shall have an operational availability of at least TBD%.	Goddin 2008	Constraint	The C2 system shall have an operational availability of at least TBD%.	

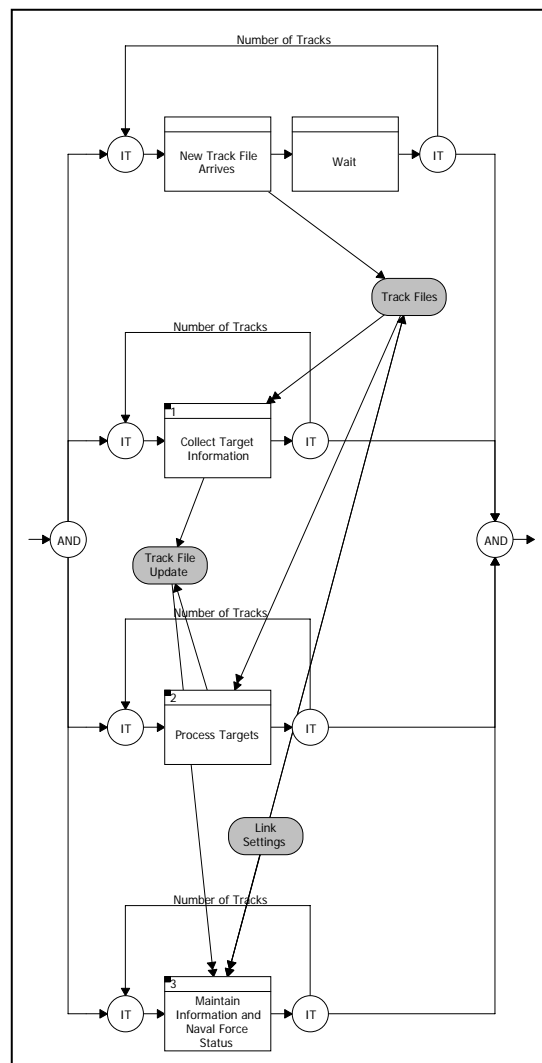
Requirement	Rationale	Type	Value System Design	Architecture Function
1.8.1.4.1 MTBF The C2 system shall have a Mean Time Between Critical Failures of greater than TBD hours.		Constraint	The C2 system shall have a Mean Time Between Critical Failures of greater than TBD hours.	
1.8.1.4.2 Mean Down Time The C2 system shall have a Mean Down Time of less than TBD hours.		Constraint	The C2 system shall have a Mean Down Time of less than TBD hours.	
1.8.2 MOSA Design The C2 system shall implement a MOSA design, while maintaining the independence of the application from the underlying computing plant.	USD (AT&L), "The Defense Acquisition System", 2003; Stockbauer 2008	Constraint	The C2 system shall implement a MOSA design, while maintaining the independence of the application from the underlying computing plant.	
1.8.3 DISR Technical Standards The C2 system shall only implement standards found in the Defense Information Systems Repository (DISR).	Stockbauer 2008	Constraint	The C2 system shall only implement standards found in the Defense Information Systems Repository (DISR).	
1.8.4 Net-Ready KPPs The C2 system shall be compliant with the Net-Ready Key Performance Parameter as listed in the table below.	CJCSI 6212.01E	Constraint	The C2 system shall be compliant with the Net-Ready Key Performance Parameter as listed in the table below.	
1.8.5 Cost KPP The C2 system cost shall not exceed \$TBD.		Constraint	The C2 system cost shall not exceed \$TBD.	

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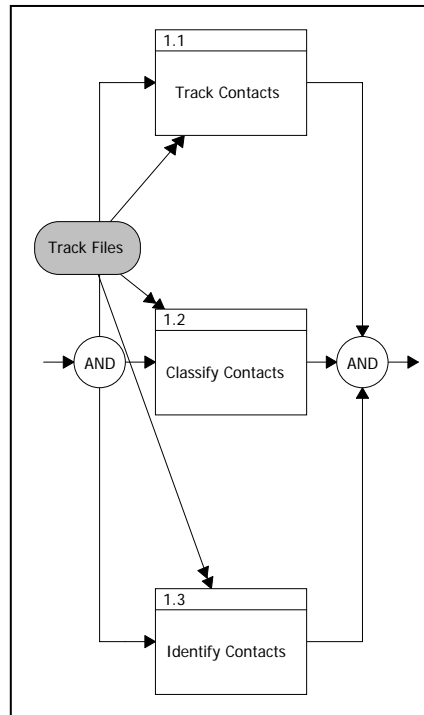
## APPENDIX D: ADDITIONAL CORESIM MODEL VIEWS

Figures 38-41 are the Enhanced Functional Flow Block Diagrams (EFFBD) for the C2 Architecture Operational Activities. The first diagram is the same as Figure 28 in the body of the report. It represents the top-level view. The next three diagrams represent the second tier of the operational activities, including Figure 29 from the body of the report.



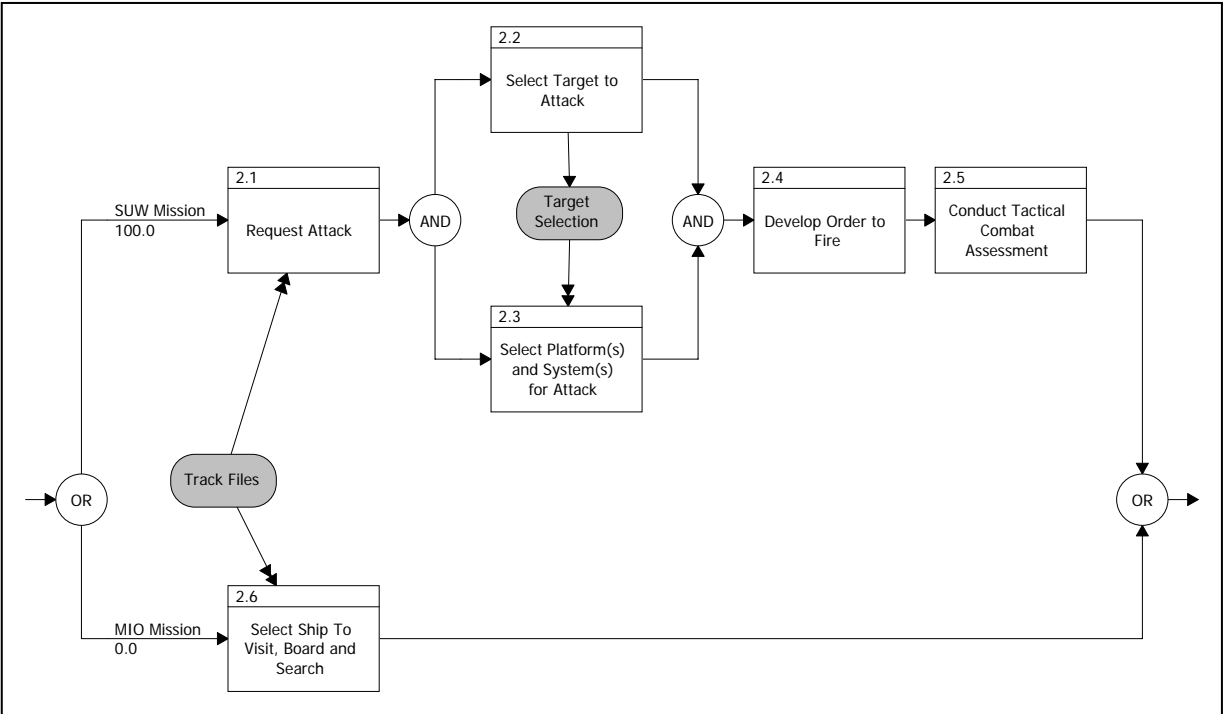
**Figure 38: EFFBD of Top-Level C2 Operational Activities**

This EFFBD displays the top-level operational activities, all executed in parallel, with iteration to support multiple successive targets



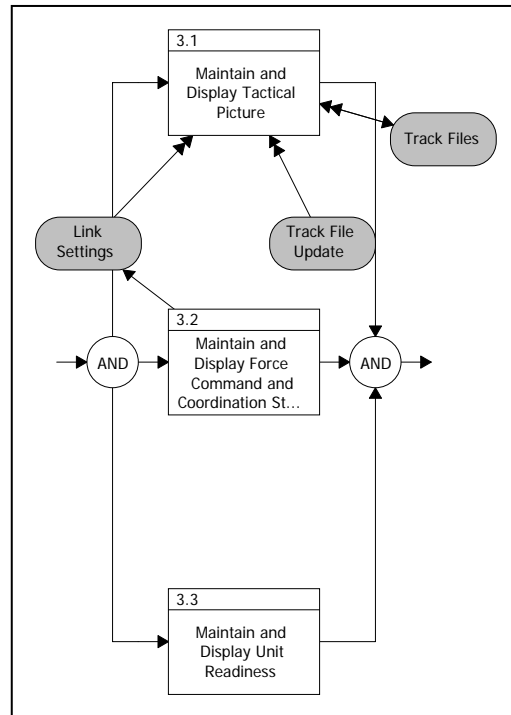
**Figure 39: Collect Target Information C2 Operational Activities**

This EFFBD is the decomposition of the “Collect Target Information” Operational Activity.



**Figure 40: Target Processing C2 Operational Activities**

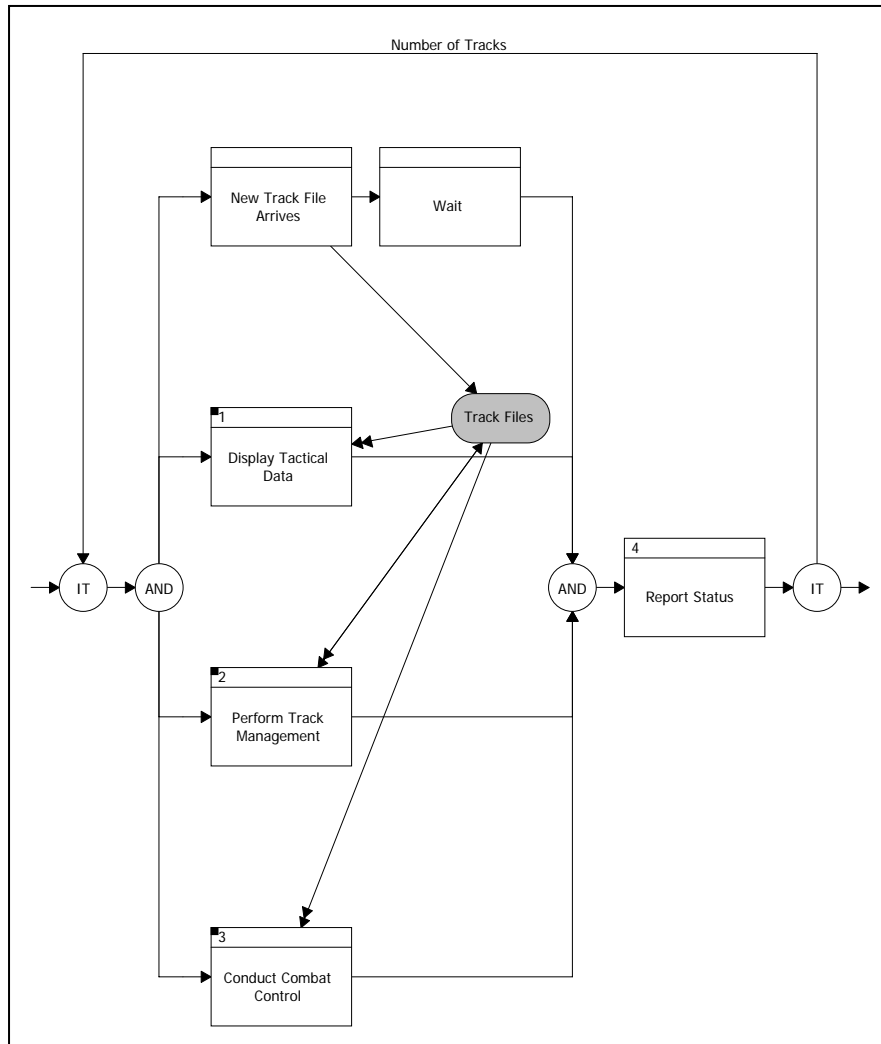
This EFFBD is the decomposition of the “Process Targets” Operational Activity. The top branch includes activities associated with the SUW mission. The bottom branch shows the activity associated with the MIO.



**Figure 41: Maintain Information and Naval Force Status C2 Operational Activities**

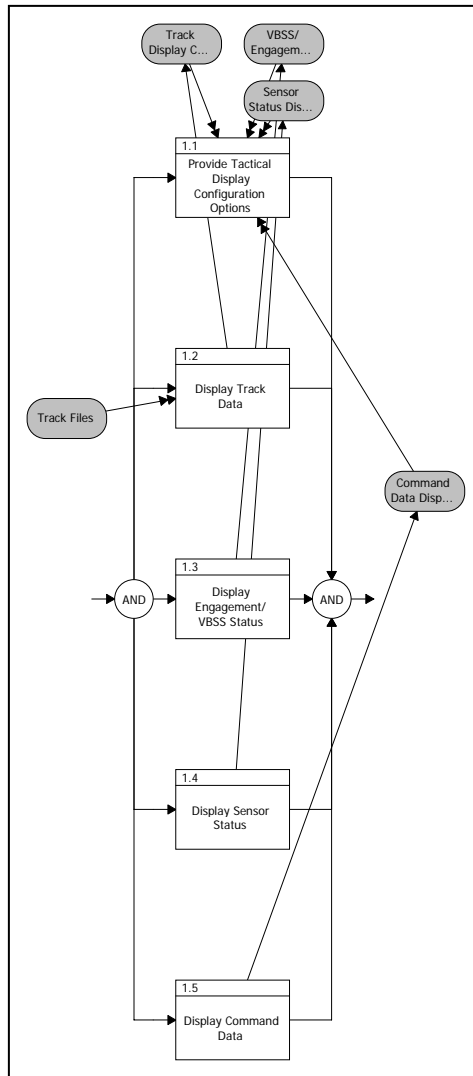
This EFFBD displays the “Maintain Information and Naval Force Status” C2 Operational Activities.

Figures 42-45 are the Enhanced Functional Flow Block Diagrams (EFFBD) for the C2 Architecture System Functions. The first diagram is the same as Figure 31 in the body of the report. It represents the top-level view. The next three diagrams represent the second tier of the system functions, including Figure 32 from the body of the report.



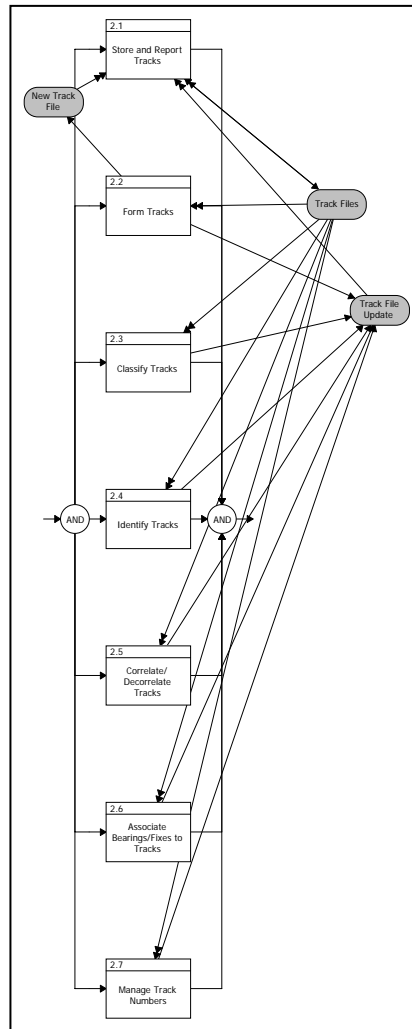
**Figure 42: EFFBD of Top-Level C2 System Functions**

This figure shows the top-level system functions as an EFFBD, where each function is executed in parallel to support multiple targets.



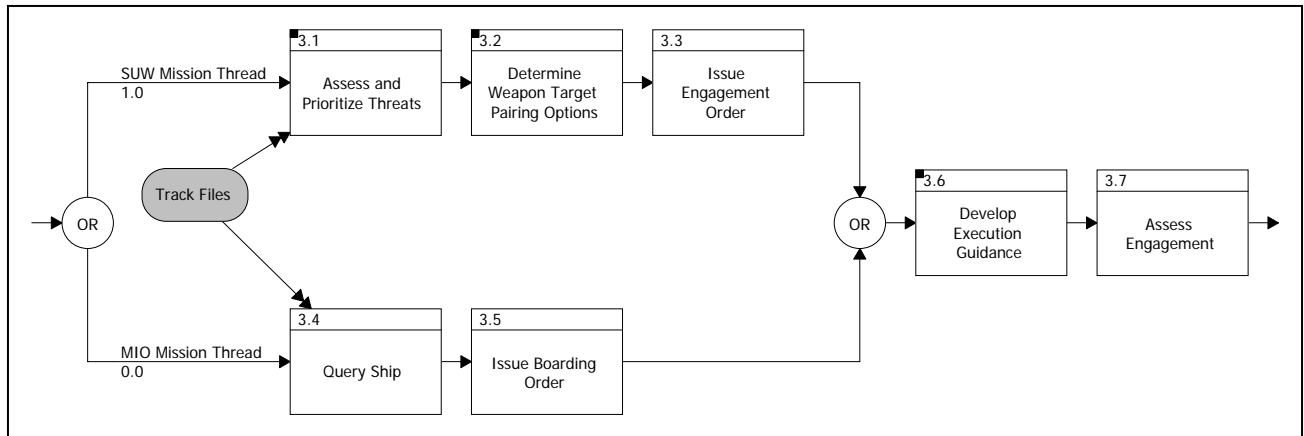
**Figure 43: Display Tactical Data C2 Functions**

This EFFBD displays the sub-functions of the “Display Tactical Data” system function.



**Figure 44: Perform Track Management C2 Functions**

This EFFBD displays the sub-functions that compose the “Perform Track Management” system function.



**Figure 45: Conduct Combat Control C2 Functions**

This figure shows the child functions of the Conduct Combat Control function. The separate branches show the functions associated with the SUW and MIO missions.



## APPENDIX E: ACRONYM LIST

Acronym	Term
AIS	Automatic Identification System
ASCM	Anti-Ship Cruise Missile
C2	Command and Control
C3	Command, Control and Communications
C4I	Command, Control, Communications, Computers, Intelligence
CBN	Chemical, Biological and Nuclear
CG	Guided Missile Cruiser
COC	Combat Operations Center
COP	Common Operational Picture
COTS	Commercial-Off-The-Shelf
CPN	Colored Petri Nets
CSCS	Center for Surface Combat Systems
CSG	Carrier Strike Group
CTP	Common Tactical Picture
DAS	Defense Acquisition System
DCO	Defense Connect Online
DDG	Guided Missile Destroyer
DISR	Department of Defense Information Technology Standards Repository
DoDAF	Department of Defense Architecture Framework
DOORS	Dynamic Object Oriented Requirements System
DWC	Distributed Weapons Coordination
EO/IR	Electro-Optical/Infra-Red
EOR	Engage on Remote
ER&A	Enterprise Requirements and Architecture
EFFBD	Extended Functional Flow Block Diagram
ES	Electronic Support
EW	Electronic Warfare
FAC	Fast Attack Craft
FFG	Guided Missile Frigate
FIAC	Fast Inshore Attack Craft
GPS IS	Global Positioning System Interface Specification
I&W	Indications & Warnings
ICOMS	Inputs, Controls, Outputs, and Mechanisms
IDEF0	Integration Definition language 0
IED	Improvised Explosive Devices
IFF	Identification Friend or Foe
IPR	Integrated Product Review
IPT	Integrated Product Team
ISR	Intelligence, Surveillance and Reconnaissance
IWS	Integrated Warfare Systems

Acronym	Term
JCIDS	Joint Capabilities Integration and Development System
JIC	Joint Integrating Concepts
JFC	Joint Functional Concepts
LNG	Liquid Natural Gas
M&S	Modeling & Simulation
MBSE	Model-Based Systems Engineering
MIC	Maritime Intercept Commander
MIO	Maritime Interception Operations
MMSI	Maritime Mobile Service Identity
MOSA	Modular Open Systems Architecture
MSSE	Masters of Science in Systems Engineering
MT	Message Type
NOC	Naval Operating Concept
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
NSWM	Navy Surface Warfare Manual
NTA	Navy Tactical Task
NTTL	Navy Tactical Task List
NTTP	Naval Tactics, Techniques and Procedures
NWP	Naval Warfare Publication
ONI	Office of Naval Intelligence
OSC	On Scene Commander
OTH	Over-the-Horizon
OV	Operational View
PEO	Program Executive Office
PLAN	People's Liberation Army Navy
PMP	Project Management Plan
POA&M	Plan of Action & Milestones
PPBES	Planning, Programming, Budgeting, and Execution System
PPR	Pre-planned Response
RCS	Radar Cross Section
RF	Radio Frequency
ROE	Rules of Engagement
ROV	Remotely Operated Vehicle
RPG	Rocket Propelled Grenade
SAG	Surface Action Group
SAM	Surface-to-Air Missile
SCC	Strongly Connected Components
SE	Systems Engineering
SEDP	Systems Engineering Design Process
SIAP	Single Integrated Air Picture
SITREP	Situation Report
SLOC	Sea Line of Communication
SSDS	Ship Self-Defense System

<b>Acronym</b>	<b>Term</b>
SSM	Surface-to-Surface Missile
SUW	Surface Warfare
SUWC	Surface Warfare Commander
SV	Standard View
TA	Technical Assistant
TBD	To Be Determined
TEU	Twenty-foot Equivalent Units
TTP	Tactics, Techniques, and Procedures
TV	Technical View
UAV	Unmanned Aerial Vehicle
USV	Unmanned Surface Vehicle
UNTL	Universal Naval Task List
VAMOSC	Visibility and Management of Operating and Support Cost
VBSS	Visit, Board, Search and Seizure
VHF	Very High Frequency
VSD	Value System Design
WMD	Weapons of Mass Destruction

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